THE MANAGEMENT OF URBAN IMPOUNDMENTS IN SOUTH AFRICA

VOLUME 2

GUIDELINE MANUAL

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Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

Impoundments in South African towns and cities are popular recreational attractions that add to the quality of life experienced by urban residents. They are also being increasingly built as the focal point of urban commercial developments. Such impoundments, however, act as receptacles for polluted runoff and discharges from upstream urban areas. The pollution frequently discharged to receiving streams can result in water quality problems in the impoundments. This not only reduces their aesthetic value, but also undermines their role as centres for recreational activities.

This Urban Impoundment Management Guideline Manual is the product of a research project carried out for the Water Research Commission to investigate the water quality problems most commonly experienced in South African urban impoundments, as well as the management techniques which can be used to address them.

The purpose of the Guideline Manual is to assist those responsible for, or with an interest in, the management of the water quality of urban impoundments. It is thus aimed predominantly at those persons in local authorities who must manage the water bodies in their areas. The Manual should also be of value, however, to developers, planners, design engineers, community-based and non-governmental organisations, academics and consultants, as well as the recreational users of urban impoundments and concerned individuals who may reside close to or within the catchment of an urban impoundment.

Common water quality problems experienced in South African urban impoundments include eutrophication, sedimentation, bacteriological contamination, aesthetics, and infrequent but serious events such as floods and accidental pollution spills.

These problems are the result of upstream activities and processes which generate wastes that enter a watercourse. This cause and effect relationship is fundamental to the understanding and resolving of water quality problems in urban impoundments. This relationship has been conceptualised in the Manual via an explanation of the waste cycle in water and placed within the context of integrated catchment management, the approach adopted by the Department of Water Affairs and Forestry in managing South Africa's water resources.

A framework for managing urban impoundments is presented, which examines the planning and design of the impoundment and how management techniques can be deployed to address water quality problems within the categories of catchment, pre-impoundment and in-lake management. Based on this framework, management strategies can then be developed by selecting appropriate techniques which correspond to the various stages of the waste cycle in water.

A range of management techniques are described in the Manual which can be used to combat commonly occurring water quality problems. Catchment management techniques address the causes of water quality problems. However, these can be costly and frequently require long periods of time to implement and take effect. Pre-impoundment and in-lake management techniques, on the other hand, focus on the symptoms of water quality problems, but tend to be less costly and show beneficial effects over shorter time periods. In practice, the urban

impoundment manager can use a combination of these techniques, which will usually require working with other role players in the catchment of the impoundment.

This Guideline Manual leads the impoundment manager through the process of data collection, water quality monitoring and data assessment. This is necessary in order to be able to identify the type, nature and severity of the water quality problem experienced, as well as the means to evaluate the success of management strategies which are put in place.

Examples of water quality problems experienced in three case study impoundments and the management techniques which have been used to address them, are described in Appendix A. A more detailed literature review of available management techniques with further references is given in Appendix B.

ACKNOWLEDGEMENTS

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Ms APM Oelofse	Water Research Commission (Chairperson)
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*Also assisted in editing the final report

The contributions of the following persons, local authorities and organisations in collecting and analysing samples from the three urban impoundments studied in detail for this project are also acknowledged:

Brakpan Town Council (Ms S de Villiers; Mr B Williamson)
Centurion Town Council (Mr F Nel)
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Institute for Water Quality Studies (Laboratory staff)

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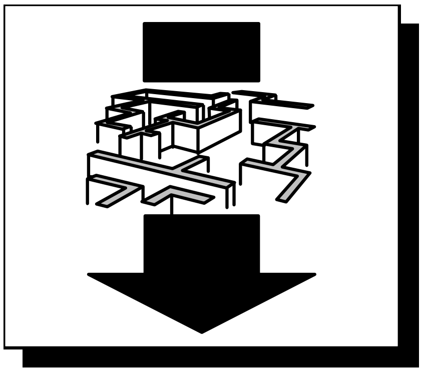
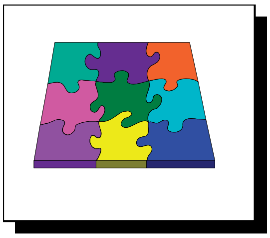


QUICK REFERENCE GUIDE

The Quick Reference Guide gives a brief overview of what the Guideline Manual is about, where information in the document is located and how the Guideline Manual should be used

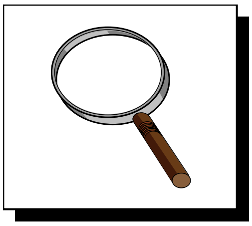
QUICK REFERENCE GUIDE

The Urban Impoundment Management Guideline Manual consists, in its main section, of two parts with supporting information in the form of two appendices, as described in summarised form below. This Quick Reference Guide contains in the following pages, a short outline of each part of the Guideline Manual, briefly highlighting its scope and contents. Also presented is a flowchart, together with an explanation of how best to use the Guideline Manual. The flowchart offers a step-by-step "road map" for urban impoundment managers to follow in tackling and addressing typical water quality problems they may encounter in the lakes and dams in their towns and cities.



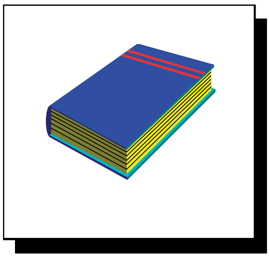
MAIN MANUAL : PART ONE (CHAPTERS 1 TO 4)

An introduction to the water quality problems most commonly occurring in urban impoundments, the context in which such problems should be evaluated and a framework within which management techniques for urban impoundments can be applied.



MAIN MANUAL : PART TWO (CHAPTER 5 TO 8)

Assists the urban impoundment manager in collecting relevant information and data to identify and analyse water quality problems, as well as to select appropriate management techniques with which to combat them.



SUPPORTING INFORMATION

APPENDIX A:
An analysis of water quality problems and management techniques at three case study urban impoundments.
APPENDIX B:
A literature review giving more details about available urban impoundment management techniques, as well as a bibliography on each technique for further reference.

MAIN MANUAL : PART ONE (CHAPTERS 1 TO 4)

What is this part of the Manual about ?

Chapter 1 : Introduction

- Explains why water quality problems have manifested themselves so strongly in urban areas and outlines for whom the Manual has been written.

Chapter 2 : Common Water Quality Problems in South African Urban Impoundments

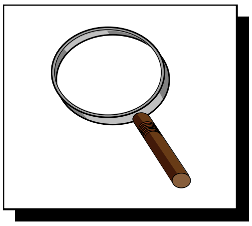
- Commonly occurring water quality problems in South African urban impoundments (viz. eutrophication, sedimentation, bacteriological contamination, aesthetics and serious pollution events) are described with examples of local impoundments which have experienced these problems.

Chapter 3 : Urban Impoundment Management Philosophy

- The need to prevent and not just control water quality problems in urban impoundments is described within the context of integrated catchment management, the policy approach now promoted by the Department of Water Affairs & Forestry.
- Water quality problems in urban impoundments largely occur because of the activities and processes taking place upstream of the impoundments. These actions result in the discharge of waste streams into watercourses, which can be prevented, reduced or controlled in terms of a management hierarchy covering the production, delivery and transport of waste to and within a watercourse or impoundment. This management hierarchy is described.

Chapter 4 : Urban Impoundment Management Framework

- Management strategies are formulated within the stepwise framework described in this Chapter. This covers impoundment planning and design (in the case of new impoundments), catchment management, pre-impoundment treatment, in-lake treatment and downstream impacts.
- Long-term timeframes generally include management strategies which address the causes of water quality problems (i.e. catchment management), whilst short-term timeframes usually address the symptoms of water quality problems (i.e. pre-impoundment and in-lake treatment).



MAIN MANUAL : PART TWO (CHAPTER 5 TO 8)

What is this part of the Manual about ?

Chapter 5 : Data Collection and Monitoring of Urban Impoundments

- In addressing water quality problems in urban impoundments, it is necessary to have a thorough understanding of the source, nature, severity and extent of the problems concerned. This Chapter outlines the information and water quality data which should ideally be collected in order to understand and assess the most commonly occurring water quality problems.

Chapter 6 : Assessment of Water Quality Data and Urban Impoundment Problems

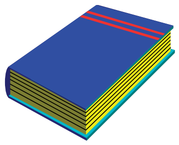
- Describes the importance of analysing water quality data and of establishing who are the users of an urban impoundment in order to set appropriate and realistic water quality objectives for the impoundment in both the short- and the long-term.

Chapter 7 : Urban Impoundment Management Techniques

- Presents a range of urban impoundment management techniques, the water quality problems they address, their positive and negative aspects, as well as the stages in the management hierarchy at which they may be used.

Chapter 8 : Basic Monitoring Programmes

- Details monitoring programmes which need to be conducted on a continuous basis in order to assess the success of the management techniques which have been implemented, and to monitor any changes taking place in the impoundment and its catchment.



SUPPORTING INFORMATION

APPENDIX A
APPENDIX B

What is this part of the Manual about ?

APPENDIX A : An Analysis of Water Quality Data and Management Techniques at Three South African Urban Impoundments

- Case studies are presented of three local urban impoundments (viz. Jan Smuts Dam, Brakpan; Hennops Lake, Centurion; and Zoo Lake, Johannesburg), which experience typical water quality problems. The case studies describe the water quality problems, the management techniques which have been implemented to tackle these problems, and assess their success to date.

APPENDIX B : A Literature Review of Urban Impoundment Management Techniques

- An international literature review of urban impoundment management techniques is presented detailing available knowledge about each technique together with an extensive bibliography for further reading.

HOW TO USE THIS MANUAL

This Manual has been structured and written as a concise and practical tool to assist urban impoundment managers. The Manual is divided into a main section (containing two parts) with two supporting appendices, as is shown in Figure A1 below:

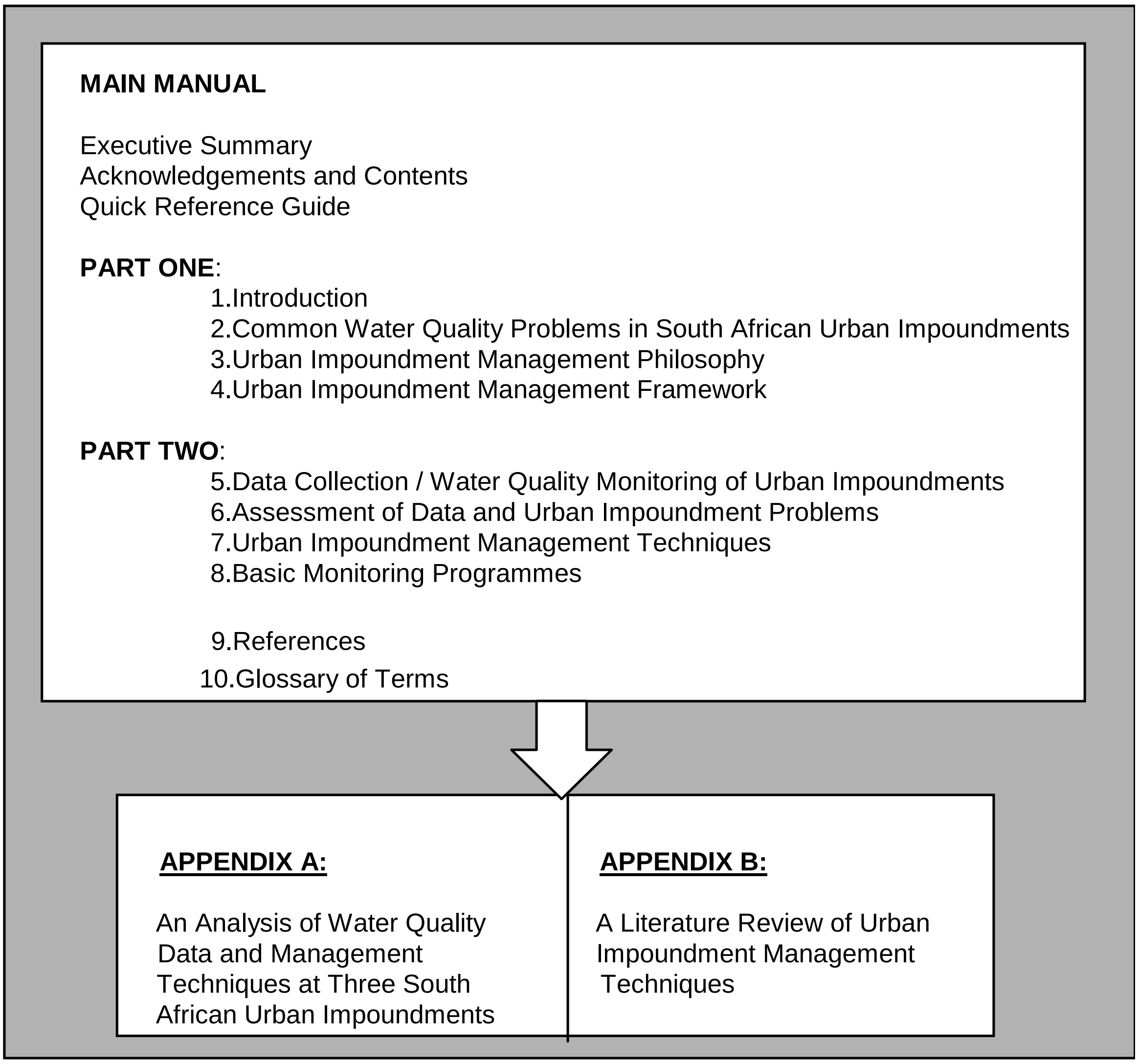


Figure A1 : Schematic of Manual Structure

- Part 1 of the main Manual is particularly useful for those who need to have a broad understanding of water quality problems as they relate to urban impoundment management.

- Part 2 of the main Manual is aimed at guiding the impoundment manager through the process of a water quality investigation, highlighting the steps and key issues in the process. The management techniques which may be used to tackle water quality problems in urban impoundments are also described in this part of the Manual.

- Supporting information in the form of a reference list, a glossary of terms and the two appendices can be used by readers who need to identify a specific publication referred to in the text (references), those who need to understand a term mentioned in the text (glossary) and those who want more information on the case study examples and subjects mentioned in the main Manual (appendices).

- A detailed flowchart to assist the reader in using the Manual is presented in Figure A2.

What is the flowchart about ?

The flowchart shown overleaf provides a quick and easy method for navigating this Manual. An understanding of the flowchart is essential in making proper use of the Manual. It combines a list of Chapters contained in the Manual with a graphic view of the steps which must be followed when investigating water quality problems in urban impoundments. In practice, however, a number of iterations (indicated by the dotted lines) may be required in order to acquire a thorough and complete understanding of the problems at hand.

Most of the flowchart is focused on Part Two of the main Manual (Chapters 5 - 8), which guides the urban impoundment manager through the steps that must be carried out when conducting an investigation into a water quality problem.

The flowchart appears again in the Manual at the start of Chapters 5, 6, 7 and 8. This is to remind the reader of the stage that has been reached in a water quality investigation and which steps of the investigation will be dealt with in the ensuing Chapter.

The last shaded box in the flowchart covers the selection of management techniques to address water quality problems in urban impoundments. These management techniques are broadly categorised into three groups, which are listed in the flowchart in descending order according to a management hierarchy. These groups are catchment management, pre-impoundment treatment and in-lake treatment. The descending arrow to the left of the flowchart indicates the broad timeframe required (from long- to short-term) before the beneficial effects of implementing a management technique from each of the three groups may be felt. The descending arrow to the right of the flowchart indicates which group of management techniques is more suited to addressing the causes rather than the symptoms of water quality problems.

FLOWCHART FOR USE OF THE MANUAL

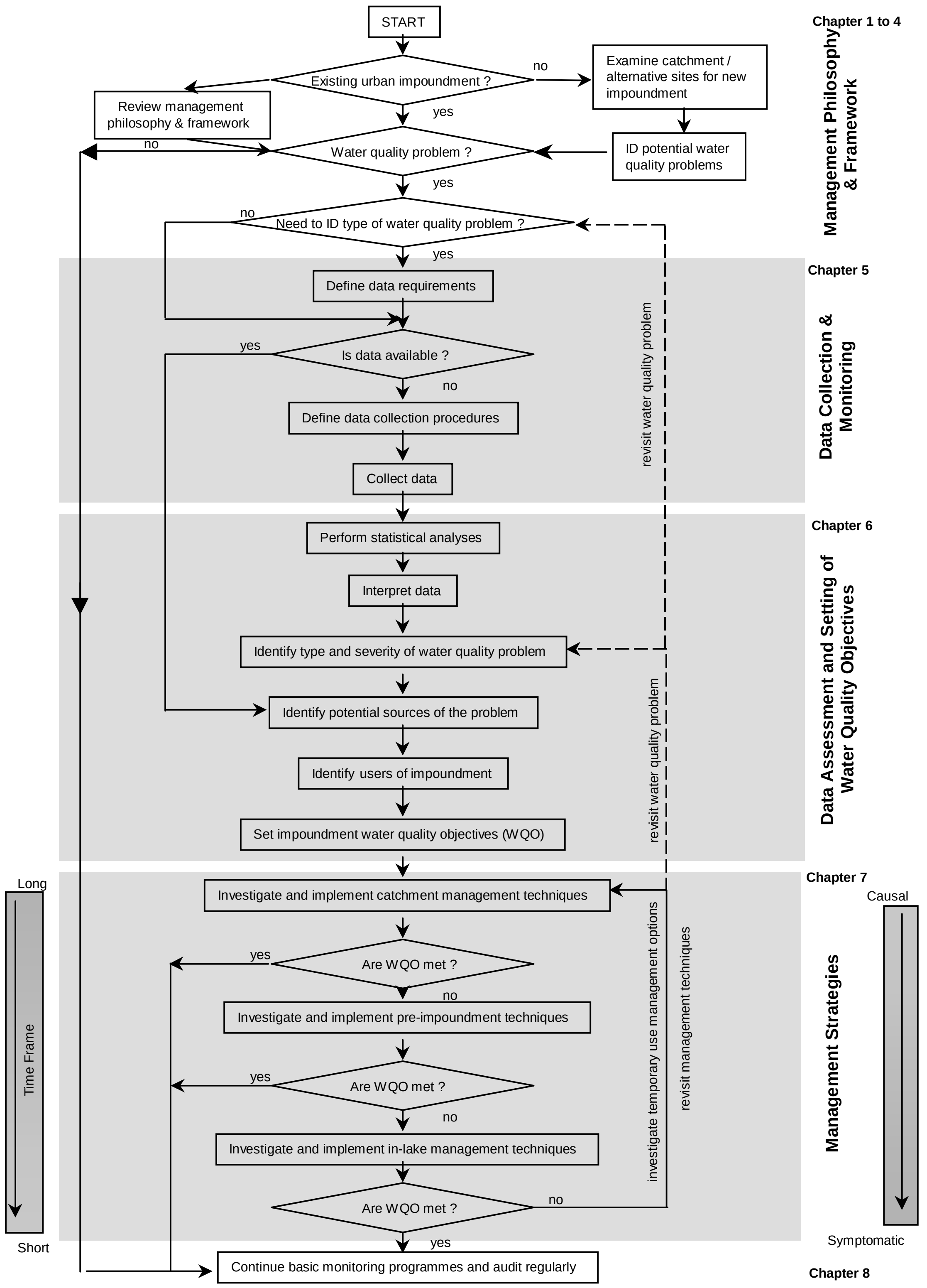
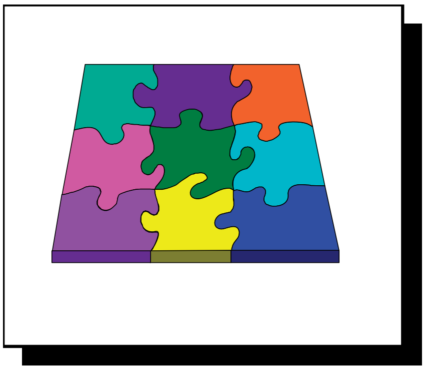


Figure A2 : Flowchart for Use of the Manual



MAIN MANUAL PART ONE

CHAPTER 1: INTRODUCTION

1.1
Value of urban impoundments

The quality of modern urban life can be greatly improved by aesthetic features such as lakes and dams. Not only do these impoundments provide a psychological escape for city dwellers from the pressures of everyday life, but they also serve as recreational attractions, which can often enhance the value of land, houses, office blocks and commercial developments in their immediate vicinity. Such impoundments also frequently have a practical use in the urban environment by assisting in the control of stormwater.

1.2
Brief history of urban impoundments

Impoundments in South African towns and cities are not recent developments. For instance, Zoo Lake in Johannesburg is a man-made impoundment that was built during the first decade of this century. Additionally, natural water bodies, such as pans and vleis, have been gradually surrounded by urban development in certain cities (e.g. North End Lake, Port Elizabeth) and these have also become important aesthetic and recreational attractions for urban residents. More recently, commercial developments have increasingly been built with impoundments as their central feature (e.g. Bruma Lake and the Randburg Waterfront in Johannesburg).

1.3
Potential water quality problems

Water quality problems associated with urban impoundments are equally not recent developments - Jan Smuts Dam in Brakpan has a documented record of such problems stretching back to 1940. Unfortunately many urban impoundments act as receptacles for upstream waste, resulting in:

- silted up impoundments;
- their enrichment with plant nutrients which often leads to the associated growth of undesirable algae and water plants (referred to as eutrophication);
- increased health risks due to bacteriological contamination; and
- aesthetic problems such as unsightly scums, floating debris and malodours.

The above problems can cause what should be a public asset to turn into a liability, and, more seriously, can pose a health risk. Such water quality problems also tend to be accentuated in urban areas where man's activities are wide-ranging, densely concentrated and frequently culminate in the generation of numerous waste streams which may enter watercourses.

1.4

The purpose of this Guideline Manual is to assist those responsible for, or

Target audience for the Manual

with an interest in, the management of the water quality of urban impoundments. It is chiefly aimed, therefore, at those persons in local authorities who must manage the water bodies in their areas. Where this responsibility lies may vary between different local authorities depending on the size of the local authority in question. For instance, in the larger authorities, the Engineering, Parks or Health Departments may manage the impoundments, or responsibility may even straddle these departments. In contrast, in the smaller local authorities, the Town Engineer may bear full responsibility for managing impoundments and may have to fulfil all the aforementioned departmental roles.

The Manual should also be of value to developers, planners, design engineers, community-based and non-governmental organisations, academics and consultants, as well as the recreational users of urban impoundments and concerned individuals who may reside close to or within the catchment of an urban impoundment.

PURPOSE OF GUIDELINE MANUAL

This document has been designed as a **user friendly Manual** which can be used as a tool in the management of urban impoundments. It is not meant to be an exhaustive reference on the topic and the reader is referred to more detailed texts on particular subjects where appropriate. A simple explanation of how best to use the Manual is given in the Quick Reference Guide preceding this introductory Chapter.

The Manual is not an academic report aimed at limnological specialists, but rather attempts to keep difficult technical concepts and jargon to a minimum for the intended audience (i.e. those responsible for managing urban impoundments in the local authorities). A reference list and a glossary of terms used in the Manual, however, are given at the end of the main document to assist the reader.

Some practical case study experiences of urban impoundment problems in South Africa are presented in Appendix A. More detailed explanations concerning water quality problems, as well as a selected bibliography on specific management techniques for urban impoundments, are presented in the literature review in Appendix B.

CHAPTER 2: COMMON WATER QUALITY PROBLEMS IN SOUTH AFRICAN URBAN IMPOUNDMENTS

2.1 Introduction

In order to select appropriate water quality management strategies and techniques for urban impoundments, it is necessary to understand the water quality problems which typically occur in them. The problems that most commonly occur in South African urban impoundments have been identified in the Water Research Commission report TT 76/96: **"The Management of Urban Impoundments in South Africa: Volume 1, Status Quo Report"**.

The Volume 1 report documents the findings of the first part of this research project in which a register of urban impoundments in South Africa was compiled together with an in-depth study of the water quality problems most frequently encountered in ten South African impoundments, as well as the management techniques used to combat them. The first part of the research project identified the most common water quality problems as:

- eutrophication;
- sedimentation;
- bacteriological contamination;
- aesthetics; and
- serious pollution events.

These problems are discussed in greater detail below.

2.2 Eutrophication

Eutrophication refers to the enrichment of a water body with plant nutrients such as phosphate and nitrogen, resulting in the excessive growth of algae or other water plants. In urban impoundments, algal scums or the explosive growth of water plants such as the water hyacinth are not only unsightly, but also interfere with the recreational use of an impoundment such as angling or rowing. Algal scums often give off unpleasant smells when they decay, whilst some blue-green algae are toxic and can cause animals (e.g. cows and dogs) to become ill and even die if they drink sufficient quantities of the affected water. Exposure to algae-infested waters can also cause diarrhoea or skin irritations in humans. For example, people taking part in contact recreation watersports such as swimming and water-skiing have become ill after swallowing affected water.

Although the most common cause of eutrophication is excessive enrichment of water bodies by wastes high in phosphate and nitrogen, algal growth is also controlled by a number of other factors, such as light availability in the water column, water temperature, the depth and shape of an impoundment and the direction and strength of the prevailing wind.

Blue-green algae generally present a greater problem in South Africa than green algae. Most blue-green algae flourish at higher water temperatures than green algae, as well as in stagnant (i.e. non-turbulent) conditions. This is why blue-green algae tend to bloom in nutrient-rich water after hot, wind-free periods, when they often form buoyant surface scums which are very visible. Unfortunately, the climate in South Africa results in water temperatures that favour the growth of blue-green algae. Urban impoundments are usually shallow water bodies with the result that no temperature gradient develops within the water body and the impoundment does not stratify.

In older impoundments, nutrients may have accumulated in the sediments on the lake floor. Under certain (usually turbulent) conditions these nutrients may be released from the sediments into the water body, and even if the nutrient concentrations in the incoming streams are reduced, excessive algal or plant growth may still occur for a number of years unless the problem of nutrient release from the sediments is also addressed. It is therefore important to identify both the external and internal nutrient sources to determine the optimum and most cost-effective way of addressing the problem.

Examples of where eutrophication problems have manifested themselves in South African urban impoundments include Jan Smuts Dam in Brakpan and Zoo Lake in Johannesburg (Photograph 1, page 2.3).

2.3 Sedimentation

Sedimentation is generally a problem in most South African impoundments. Natural vegetation is sparse over much of the country leaving areas of soil exposed and prone to erosion. Such exposure can, in turn, be aggravated by overgrazing. Rainfall often occurs as flood events, leading to soil erosion and the washoff of sediment from areas not covered by vegetation.

Sedimentation also occurs in towns and cities as a result of construction and other urban activities, and accumulates in runoff over urban surfaces.

Photograph 1: Eutrophication in Zoo Lake, Johannesburg

Photograph 2: Sedimentation in Hennops Lake, Centurion

An increase in sediment in an impoundment has the following negative effects:

- reduction in the impoundment depth;
- reduction in stormwater control capacity;
- interference with recreational activities;
- suffocation of submerged plants and aquatic life, thereby changing the ecological balance in the impoundment; and
- trapping of nutrients in the sediments which may in future contribute to excessive algal growth when released.

Camps Drift Canal in Pietermaritzburg and Hennops Lake in Centurion (Photograph 2, page 2.3) are examples of where sedimentation problems occur in South African urban impoundments.

2.4 Bacteriological contamination

Bacteriological contamination of urban impoundments can originate from a number of sources such as the effluent from wastewater treatment works, blocked sewers and drains causing raw sewage to run into streams (Photograph 3, page 2.5), washoff from animal feedlots and informal settlements with inadequate sanitation facilities, or direct contamination from human and animal waste.

Excessive bacteriological concentrations in water affect human health due to the presence of pathogens which can cause diarrhoeal and respiratory problems and eye, ear, skin or wound infections. Measuring the presence of coliform bacteria in the water is usually a good indicator of the bacteriological health of an impoundment.

Bacteriological contamination is frequently a problem in urban impoundments where coliform levels not only remain high but where the impoundments are also used intensively for contact recreation watersports (e.g. water-skiing, swimming). In addition, contamination of urban impoundments with viruses and parasites can occur. Examples of where bacteriological contamination of urban impoundments has occurred, include Zoo Lake in Johannesburg and Hennops Lake in Centurion.

2.5 Aesthetics

Aesthetic problems at urban impoundments are largely the secondary results of the underlying water quality problems described above. Typical examples of aesthetic problems include:

- obnoxious odours from decaying algae or hydrogen sulphide released from bottom sediments;
- visual impacts from algal scums, dead fish and debris trapped in the scums; and
- visual impacts from litter and suspended sediment.

Photograph 3: Leaking sewers can cause bacteriological contamination in downstream impoundments

Photograph 4: Aesthetic problems caused by litter at Zoo Lake, Johannesburg

Poor aesthetics can usually be dealt with by solving the underlying water quality problem such as excessive nutrient or suspended sediment concentrations. Litter control, however, is largely an education and enforcement issue together with adequate litter management.

Frequently visited urban impoundments with heavily populated catchments, such as Zoo Lake in Johannesburg, often suffer from poor aesthetics as a consequence of littering (Photograph 4, page 2.5).

2.6 Serious pollution events

A serious pollution event (e.g. a flood; an accidental chemical spill) is characterised as a once-off, high-intensity occurrence, the consequences of which can negatively affect both the water quantity and its quality in an urban impoundment.

It is difficult to foresee and plan for the effects of these disruptive events on the water quality of an urban impoundment due to their unpredictable and isolated nature. Nevertheless, a precautionary approach can be taken by introducing flood control measures, recording the presence of high-risk activities or industrial processes in the catchment (or close to an impoundment) and by having the necessary equipment and resources on hand to respond to unforeseen disasters. The risk can be further reduced by having adequate on-site control measures (e.g. diversion channels) to help contain any unexpected pollution incidents.

Such events can involve the accidental release or spillage of liquids or toxic waste which can seriously pollute or contaminate an impoundment. Low oxygen levels in the water and rapid temperature changes may result from the sudden release of such substances or wastes. These rapid and significant alterations to the aquatic environment may manifest themselves visually in the form of fish kills and the death of large numbers of other aquatic animals, and may persist long after the event.

Blue Dam in Johannesburg suffered the results of such a serious event in 1994 when the impoundment became severely contaminated with both oils and other liquids washed into the impoundment as a consequence of efforts to extinguish a fire at a nearby warehouse (Photograph 5 on facing page).

Photograph 5: Pollution of Blue Dam, Johannesburg after a fire at a nearby warehouse

2.7
Other problems

Other water quality problems which may occur in South African impoundments include the presence of high levels of salts, metals, pesticides and radionuclides as a result of waste discharges by industries and mines and runoff from intensively farmed areas. High levels of these constituents do not usually pose an immediate or significant threat in terms of recreational activities (the predominant use of urban impoundments). However, should water be abstracted from an impoundment for other specific uses, it may be necessary to first treat this water. The presence of such constituents may also constitute a long-term threat to the ecological health of an impoundment.

It should also be remembered that water quality problems, and the chemical and biological interactions and processes which take place in an urban impoundment, may have implications for downstream water quality. An example is the slow release of accumulated metals trapped in the sediments of an impoundment. Such a process can have unforeseen downstream effects and have longer term and complex implications for management.

CHAPTER 3: URBAN IMPOUNDMENT MANAGEMENT PHILOSOPHY

3.1 Introduction

The water quality in a lake or dam is predominantly the result of upstream activities and processes, which generate pollutants or wastes that enter a watercourse. This cause and effect relationship is fundamental to the understanding and resolving of water quality problems in urban impoundments. Upstream activities and processes (i.e. the causes) may be natural and/or man-made (anthropogenic). Man-made activities usually involve either the production of a new waste stream or the acceleration of a natural waste stream. The net results (i.e. the effects) can be seen as changes in downstream water quality, often resulting in the problems described in the previous Chapter.

In South Africa, to date, the management of urban impoundments has tended to focus on the treatment of the symptoms of water quality problems, i.e. in-lake treatment, rather than waste prevention or source control. This approach does not address the causes of water quality problems.

3.2 Integrated catchment management

A pro-active management philosophy for urban impoundments is therefore recommended. Such a philosophy has been developed for the purposes of this Manual within the context of the Department of Water Affairs and Forestry's (DWAF's) approach of **integrated catchment management.** DWAF is currently reassessing its policy on water quality management through a review of South Africa’s water law, and it must be recognised that this Manual is being written in a time of change in terms of water resource management policy.

Despite this reality, a fundamental principle has been recognised and accepted at national level with regard to water quality management and that is that the catchment must form the basic management unit.

A catchment is viewed as a living ecosystem, which means that it is a large, interconnected web of land, water, vegetation, habitats and biota, which are linked by many physical, chemical and biological processes. Understanding such a system means recognising that a disturbance made at one place in the system will be translated to other parts of the system. Thus the physical, chemical and biological characteristics of a river system change progressively and cumulatively along its length as the water is altered by land use, runoff, water abstractions and effluent discharges.

These processes of change link the different components into an integrated system which not only includes the water and biota in the river system, but also all of the human activities and natural processes in the catchment which affect the quantity and quality of the water. All of these features need to be taken into account when the water resource is managed (DWAF, 1996).

Since the water quality in an urban impoundment is affected by a multitude of waste-generating activities and processes taking place upstream of the impoundment, the most effective way of dealing with the resulting water quality problems is to look at the entire picture (i.e. the catchment) and not just at the impoundment in isolation.

It is important, therefore, for the urban impoundment manager to understand the current thinking underlying integrated catchment management, where activities and processes which produce the wastes that impact on downstream water quality, can be conceptualised in terms of the waste cycle and under the following headings (Quibell *et al*., 1997):

- production;
- delivery;
- transport; and
- use.

3.3 Waste cycle in watercourses

Pollution or waste originates from the place where it is **produced**, whereafter it is **delivered** via natural runoff, or by means of a man-made pipeline or channel, to a receiving water. After delivery, waste is **transported** and can be transformed within the receiving stream until it reaches the impoundment, where it may impact upon the **use** of the water (Quibell *et al.*, 1997).

Each of the stages in the waste cycle is explained in more detail below.

3.4 Production

Production refers to the actual place where waste is produced. This may be a point source such as an industrial plant or a wastewater treatment works, or a diffuse (non-point) source such as paved urban surfaces or fertilised fields. Non-point sources which impact on water quality can result from any activity which produces wastes that enter the receiving water body in an intermittent or diffuse manner. Non-point sources usually arise during wet weather events which cause the surface washoff of the wastes (DWAF, 1995).

Some typical local examples of situations where wastes are produced and the impoundments that are ultimately affected are described below.

- The generation of wastewater by industry and the pumping and discharge of underground water by mines are common examples of situations where waste is produced. The gold mining industry situated in the Johannesburg area, for example, discharges underground mine water to nearby watercourses and this ultimately affects the water quality of many impoundments in southern Gauteng, because such water is generally high in salts and/or metal concentrations.

- Although wastes containing coliforms, ammonia, and phosphate are released to watercourses by wastewater treatment works, they are actually produced to a large extent by humans in their homes, whereafter the sewage (the waste) is treated by the works. The treatment works therefore act as an essential intermediary between the actual production of the waste, and the point of delivery. It should be remembered that the discharge of treated sewage back to watercourses in South Africa is a requirement of the Water Act (No. 54 of 1956), because of the scarcity of water resources in the country. Many impoundments in urban areas, however, are affected by the upstream discharges of wastewater treatment works (e.g. Nigel Dam, Nigel), whilst some impoundments receive treated sewage directly (e.g. Jan Smuts Dam, Brakpan).

- A more diffuse source of waste which may be produced in significant quantities in urban areas is animal waste and litter (e.g. Zoo Lake, Johannesburg). Waterfowl and/or livestock defecating directly in the water or on the shores of an impoundment, or faeces from dogs being deposited in the area immediately surrounding an impoundment, is often washed into the water body and contributes to bacteriological contamination in the impoundment. Impoundments heavily utilised for recreation also frequently suffer from litter pollution which contributes to aesthetic problems and malodours.

  Examples of waste produced by non-point sources include runoff and seepage from slimes dams (e.g. Wemmer Pan, Johannesburg) and solid waste disposal sites (e.g. Jan Smuts Dam, Brakpan), sediment originating from poor farming practices, badly managed construction sites or poorly serviced townships (e.g. Hennops Lake, Centurion) and phosphorus and nitrogen-rich runoff from fertilised fields (e.g. Zeekoevlei, Cape Town).

3.5 Delivery

Delivery refers to the process of introducing waste into the aquatic environment (Quibell *et al*., 1997). Delivery can be in the form of a point discharge such as a pipeline conveying effluent from a factory or a wastewater treatment works, or it can be in diffuse form such as the runoff from fertilised land or urban surfaces.

Because wastes from non-point sources can accumulate during dry weather periods, a time lag may exist between when wastes are released from their source and their appearance in a receiving water body (DWAF, 1995). The impact on a watercourse or impoundment of waste delivered from a point source can be quantified by calculating the "waste load". The impact of waste delivered from diffuse sources is, by its very nature, more difficult to measure and quantify.

An assessment can be made of the waste load and the relative impact of both point and diffuse waste sources by measuring the water quantity and quality of the water body into which the waste is delivered, as well as the quantity and quality of the waste stream itself. This is done by taking flow measurements and analysing the water quality concentrations of relevant constituents. It is important to have a knowledge of the relative contribution from the various waste sources, and to quantify these, so as to develop a management policy that can concentrate on those activities that have the greatest impact on the receiving water.

3.6 Transport

Transport refers to the movement of wastes in rivers or impoundments. During the transport process, waste can be diluted and/or undergo some form of biological, chemical or physical change. As each watercourse or impoundment is unique, the degree of change will be different for each water body, depending on the characteristics of that particular water body. Thus each system has a different capacity for assimilating wastes. Effective management of the transport of wastes requires quantification of this assimilative capacity. As no two systems will behave in exactly the same way, the assimilative capacity is often determined by simulating transport processes with the aid of the results of a water quality monitoring programme and a mathematical model (for example QUAL2E).

3.7 Use

Use forms the final element of the cause and effect relationship and refers to the action of using the water and the resulting impact of water quality on the user. It can involve using water either in a water body or impoundment (e.g. recreation or livestock watering) or following abstraction (e.g. domestic/industrial water supply or irrigated agriculture). The aquatic ecosystem itself and its associated environment may also be regarded as a user that requires certain minimum conditions to be able to function. Management actions to protect or improve water quality *in situ,* however, can only truly be aimed at the production, delivery and transport elements of the waste cycle. Management with regard to the use of water tends to be passive (e.g. use avoidance) or involves further treatment of the water outside of the natural environment (e.g. by water purification following abstraction).

3.8 Urban impoundment management hierarchy

Conceptually, it is in the long-term more effective and ultimately cheaper to manage waste at the production and delivery stages, and this has been recognised via the "polluter pays" principle now being adopted by DWAF as part of its integrated catchment management policy approach. It is logical, therefore, that the management of urban impoundments should also conform to this approach.

The elements in the waste cycle of production, delivery, transport and use are not separate or discrete along a watercourse (Pegram *et al.*, 1997). There may be significant overlap (in space and time) in both the location and processes associated with the different elements. This can complicate waste characterisation and quantification within a water body, although this step still provides the knowledge base for water quality management. It does not reduce the value of separating these elements within the waste cycle, however, in terms of a hierarchy of management, beginning with options to prevent waste (production), followed by waste minimisation (delivery) and with the remediation and treatment of water bodies (transport and use) as a last resort. Each of these elements are briefly discussed below in terms of management.

3.9 Production management

Production of waste occurs before it reaches the aquatic environment and, therefore, before it is mobilised away from the point of origin. As such, production management forms part of a source control strategy, which is aimed at preventing or minimising the amount of waste at the point of origin. Although this is the ideal point at which to manage waste and prevent subsequent pollution, the quantification and management of waste production is generally not yet well advanced in South Africa and institutional and legislative arrangements to enforce this process are still being established (Quibell *et al.*, 1997). Some examples of production management would include water reuse, waste isolation or recycling and contour ploughing. In some instances, such as with the production of human wastes, it is not practically possible to address the problem at the point of production. A more viable option would therefore be to address the problem at the point of delivery.

3.10 Delivery management

Management at the point of delivery involves the reduction or minimisation of the waste load reaching the aquatic environment. Delivery management thus occurs after the production of the waste, but before it has reached the aquatic environment. For point sources, management usually takes the form of general or special effluent standards (e.g. the 1 mg/ℓ Special Phosphate Standard), which are administered by DWAF. The reduction of waste loads from non-point sources is more difficult, and relatively little has been done in South Africa to date to control or manage the delivery of waste from diffuse sources.

A comparison of waste production with waste delivery can indicate where little is being done to limit the impacts of land use on the water environment. When the waste delivery to waste production ratio is low, waste delivery management is effective. Conversely, where this ratio approaches unity, little is being done to manage the delivery of wastes. These analyses can thus also focus attention on areas where waste production management should be promoted.

In a situation where an urban impoundment is suffering from acute water quality problems, a local authority may utilise by-laws to apply more stringent regulations with regard to waste production and delivery than those which prevail at national level. If management at the point of delivery is not successful, however, or not practically possible, the next point to address is transport of the waste.

3.11 Transport management

For urban impoundments, the management of the transport element of the waste cycle would, in practical terms, focus either on the water quality of the inflow to an impoundment or on the transport processes that occur within the impoundment itself.

The management of the transport element, however, focuses on the fate of wastes once they are already in the aquatic environment and is therefore not consistent with a source-directed management philosophy. It may nevertheless be necessary to manage both the transport and use processes in highly impacted catchments and impoundments where flow is dominated by effluent. In urbanised catchments, the concentration of point and diffuse waste sources may make it difficult and uneconomic to achieve in-stream water quality objectives by production and delivery management alone. It is at this point in particular where the impoundment manager can play a decisive role.

3.12 Use management

Use management may require treatment to make the water fit for its intended use or may involve the avoidance of poor quality water (Quibell *et al.*, 1997). Typical examples are treatment of water to potable standards, or the use of variable off-take levels to enable abstraction of water of a better quality. An example of passive use management is the erection of signs to warn against certain uses of poor quality water (e.g. for contact recreation). Management of water quality at the point of use only becomes necessary once the water quality has deteriorated beyond a certain standard. Management at the point of use should therefore only be used as a last resort, i.e. if management of the production, delivery, and/or the transport of wastes fails, or is impractical.

3.13 Management constraints

Although following the hierarchy of management steps outlined above reflects the ideal approach towards managing urban impoundment water quality problems, in practice the urban impoundment manager may be constrained by various factors which limit the range of available management options.

In crisis situations, after a serious pollution event, for example, or in response to a public outcry regarding water quality problems in an impoundment, the responsible authority may feel obliged to implement short-term solutions. These would tend to focus on management techniques which predominantly address only the transport and use elements of the management hierarchy.

This is understandable when decision makers need to be seen to be reacting swiftly to problems which are both visible and newsworthy. In addition to the time consideration, transport and use management techniques may be the cheapest available alternatives, which tend to make them more attractive.

Such short-term measures, however, will not address the causes of water quality problems and the urban impoundment management hierarchy should not be ignored or undermined by an urgent need to resolve a pressing water quality problem.

Matters can be further complicated when several management techniques (which address one or more elements of the management hierarchy) are introduced in parallel. Although such a strategy happens frequently in practice and may be successful, it makes it difficult to attribute any resulting improvement in water quality to an individual management technique.

Another commonly faced constraint in the management of urban impoundments is that the catchment may stretch across several local authority boundaries which, unless co-operation is established between neighbouring authorities, places the management of upstream processes and activities out of the jurisdiction of the urban impoundment manager. Furthermore, DWAF acts as the custodian of water resources in South

Africa at national level in terms of both quantity and quality. DWAF is thus ultimately responsible for the management of water resources at catchment level and also controls the issuing of discharge permits for waste generators.

These institutional realities frequently mean that the impoundment manager at local authority level needs to work with neighbouring local authorities and DWAF in order to fully address the hierarchy of management steps and to prevent being confined in practice to utilising management techniques which focus only on the transport and use elements of the management hierarchy. This requirement is now being facilitated to some extent through the demarcation by DWAF of river catchment management units and the establishment of "catchment forums", on which all interested and affected parties may be represented.

Many urban impoundments will form a component of these catchment management units and the forums will provide a mechanism by which the urban impoundment manager can alert other authorities to specific impoundment problems.

The urban impoundment manager should strive to design management strategies, wherever possible, which recognise and underpin the integrated catchment management approach and the hierarchy of urban impoundment management steps described earlier in this Chapter. This may entail devising a management strategy for an impoundment in collaboration with DWAF, neighbouring local authorities and other stakeholders, and which preferably addresses all waste-generating processes and activities in the catchment that impact on the impoundment, i.e. the elements of production, delivery, transport and use.

CHAPTER 4: URBAN IMPOUNDMENT MANAGEMENT FRAMEWORK

4.1 Introduction

The urban impoundment management philosophy described in Chapter 3 can be most easily realised in terms of management strategies which are formulated within the following framework:

- impoundment planning and design;
- catchment management;
- pre-impoundment treatment;
- in-lake treatment;
- short- and long-term management timeframes; and
- downstream impacts of impoundment management.

Suitable management strategies are those devised and put into practice by identifying and quantifying water quality problems through data collection and analysis (see Chapters 5 and 6) followed by the selection of appropriate management techniques (Chapter 7) within the philosophical approach explained in Chapter 3 and the framework set out above. This process is further explained in the following pages.

As the catchment, physical characteristics and surrounding environment of each urban impoundment are unique, a management framework is required within which the cause and effect relationship that results in water quality problems can be analysed and investigated. Management strategies can then be developed by selecting appropriate management techniques which correspond to the elements in the waste cycle of production, delivery, transport and use described in Chapter 3. The framework proposed is that of catchment management, pre-impoundment treatment and/or in-lake treatment within either short- or long-term timeframes, whilst taking account of the downstream impacts of selected management strategies. A further important aspect is whether the impoundment is existing or proposed. In the case of new impoundments, appropriate planning and design should be built in at the outset to assist in water quality management.

4.2 Impoundment planning and design

The management of new man-made urban impoundments should start at the planning and design stage, before they are constructed, since many of the problems commonly experienced with urban impoundments can be prevented or at least mitigated by appropriate design.

As a result of recent regulations (Government Gazette No 18261 of 5 September 1997) promulgated under the Environment Conservation Act

(No. 73 of 1989), it is now a requirement that an environmental impact assessment (EIA) is undertaken for developments such as dams or schemes affecting the flow of a river (DEAT, 1997). Such an EIA forms part of the Integrated Environmental Management (IEM) process required by the Department of Environmental Affairs and Tourism (DEAT) in assessing development projects (DEA, 1992). The IEM process has been designed to ensure that the environmental effects of activities and development proposals are taken into consideration before decisions are taken regarding their implementation. It also entails the examination of alternatives, the identification of mitigatory measures and the involvement of interested and affected parties in the decision-making process.

In carrying out an EIA for a new urban impoundment (Figure 4.1), maximum use should be made of available information and water quality data concerning the catchment of the proposed impoundment so that alternative sites for the impoundment can be investigated. In the absence of existing data, a water quality monitoring programme should be implemented. An analysis of all available data should then be conducted on a catchment basis as this will help identify potential water quality problems.

If an acceptable site for the impoundment is selected, any required mitigatory measures to prevent water quality problems can then be incorporated, where practical, into its design. These measures could affect the location, size and shape of the impoundment or involve the inclusion of features designed to perform particular functions.

For example, during the planning and design stages of the Camps Drift Canal in Pietermaritzburg, it was identified that significant sediment loads could be expected in the river and that this would ultimately result in the silting up of the impoundment. A mitigatory measure included in the design of the impoundment was the construction of a pre-impoundment settling basin, which could be periodically dredged to remove incoming sediment.

4.3 Catchment management

In terms of the management philosophy outlined in this Manual, the production and delivery of waste usually takes place in the catchment upstream of an impoundment. Thus, if waste is to be actually prevented or minimised and not just controlled, the management strategy for an impoundment must first focus on the catchment as the basic management unit.

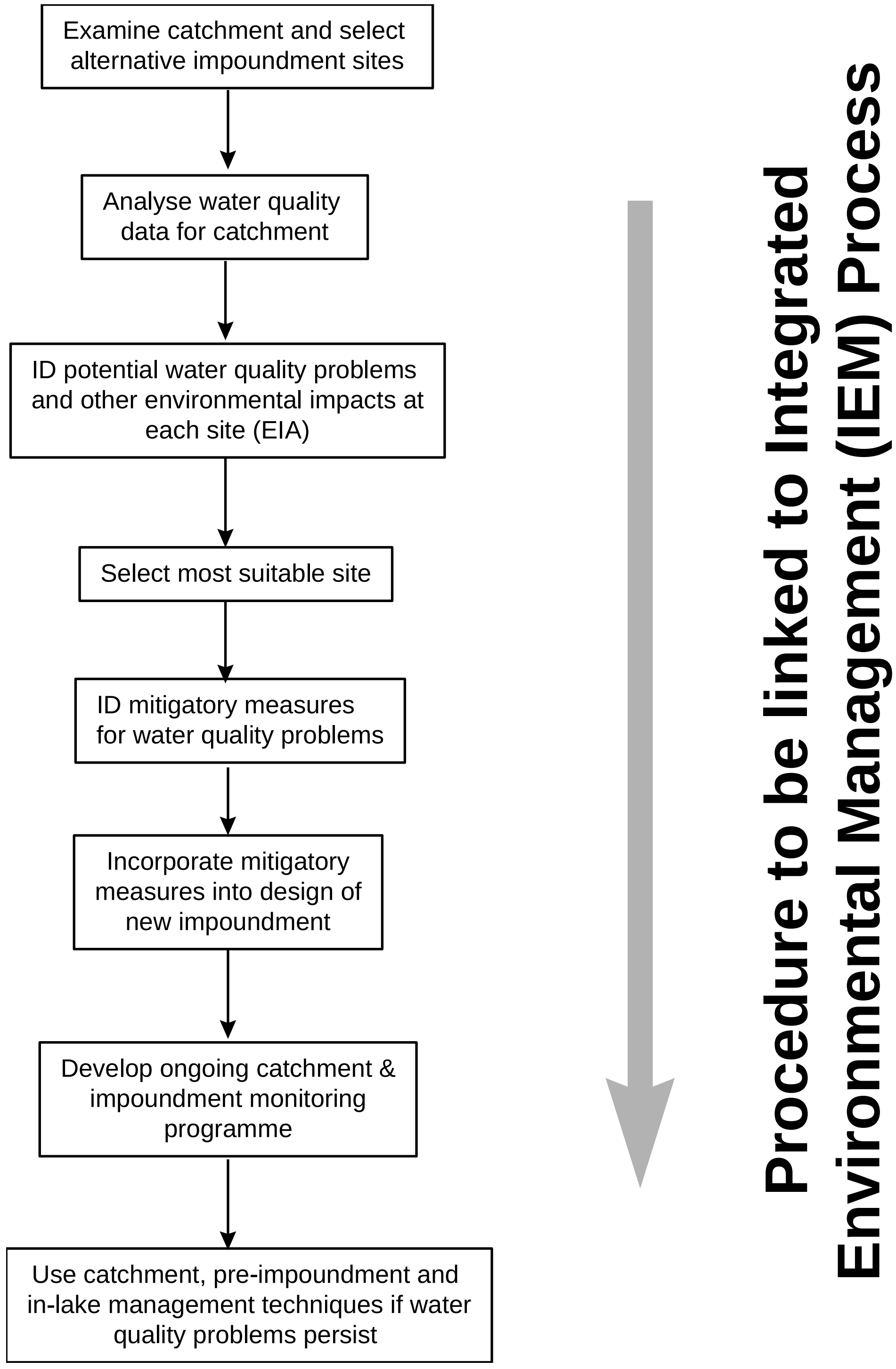


Figure 4.1 : Procedure for Planning and Designing New Urban Impoundments

This is frequently problematic, however, since local authorities who are usually responsible for managing urban impoundments often do not have the necessary powers or authority to regulate the production and/or delivery of wastes in the entire catchment, much of which may be outside their area of jurisdiction. A good example of this situation can be found on the East Rand in Gauteng, where some of the many impoundments and natural pans in this urban district form part of a single drainage area or catchment, yet are located across more than six local authority areas.

Even in situations where the necessary regulatory control can be exercised, it may be difficult to do so because of a local authority's own internal management structure. For instance, though an impoundment may fall under the control of a particular local authority, different departments in the authority may be involved in the management of the impoundment. The impoundment itself may fall under the Parks and Recreation Department, for example, whereas pollution control may be the responsibility of the Health Department. Thus careful planning and co-ordination of the activities of various departments is required to ensure effective management of an urban impoundment.

This situation could be resolved to a certain extent by the appointment of a person dedicated to the management of the urban impoundment. Such a person or "lake manager" would not work for any specific department. His/her main task would be that of identifying existing and potential water quality problems in a local authority's impoundments, as well as co-ordinating the activities of the various departments to solve or prevent these problems. This approach is being adopted increasingly in North America in order to successfully manage urban impoundments (NALMS Listserver, 1996). For management at catchment level, it would be important for the "lake manager" to work with neighbouring local authorities and the provincial and national authorities (of DWAF) in order to implement effective management. As mentioned in Chapter 3, DWAF is already establishing "catchment forums" to manage the water resources of river systems for all users.

In ideal circumstances, the "lake manager" would have a dedicated budget to manage the impoundments in his/her area of authority. Given the current priorities and budget constraints facing many local authorities in South Africa, however, it is unlikely that such a budget could be successfully motivated at present. Where capacity and funds are scarce, therefore, it may be necessary, as has also been tried overseas, to involve the private sector and members of the public (NALMS Listserver, 1996). This approach may be particularly effective where the impoundment forms part of a commercial development and the poor water quality of the impoundment affects the revenue of the surrounding commercial enterprises. Equally, where problems at an impoundment are such that the local public is concerned enough to mobilise in search of a solution, these energies and resources can be tapped in resolving problems.

The production and delivery of waste from point sources such as industries and wastewater treatment works are usually controlled by means of effluent standards set and monitored by DWAF (see Chapter 7) and as such are outside the jurisdiction of the local authority managing an urban impoundment.

Furthermore, institutional arrangements with respect to water quality management are changing as a result of the review of South Africa's water law. In certain circumstances, however, local authorities do have the discretion, through local by-laws, to impose stricter standards where appropriate (e.g. in Johannesburg all industrial effluent must first be routed via the sewer system to wastewater treatment plants for treatment before being discharged to rivers).

The management of the production and delivery of diffuse source wastes is more problematic and complex. As a consequence, less attention has been focused by the authorities on this area. Research (Wright, 1996; Smisson, 1990) is increasingly being carried out, however, both in South Africa and overseas on new methods to manage stormwater, while traditional urban planning practices are being re-thought (see Chapter 7).

4.4 Pre-impoundment treatment

Pre-impoundment treatment focuses on improving poor quality water before it is allowed into the impoundment. As such, pre-impoundment treatment addresses predominantly the transport element of the management philosophy described in this Manual, as well as the delivery element to some extent (e.g. where waste is discharged directly into an impoundment).

The impact of wastes from point and non-point sources can be minimised within a flowing river to some degree by pre-impoundment treatment, and a range of management techniques is available to the impoundment manager. These are described and examined in Chapter 7 of this Manual.

4.5 In-lake treatment

In-lake treatment focuses mainly on (although it is not restricted to) manipulating chemical and biological processes within a water body to minimise the impact of wastes on the impoundment. In-lake treatment therefore constitutes **control** of waste, and not **prevention.** Control of wastes, especially in an urban impoundment, may often seem like a futile exercise unless the causes upstream are addressed at the same time, because the treatment has to be repeated on an on-going basis. Treatment also has to be 100% effective (something which is virtually impossible to attain in practice) if the cumulative effects of the wastes are not to render the impoundment unfit for its intended use. For instance, if the impoundment is silting up (such as Hennops Lake, Centurion), the problem can be alleviated by dredging the impoundment, but unless the high sediment concentrations entering the lake are also addressed, the problem will re-occur once more in a few years' time.

Nevertheless, there are several in-lake management techniques which may be used to ameliorate water quality problems and these are also described in Chapter 7 of the Manual. In many instances, these may be the only options immediately available to the impoundment manager to resolve water quality problems and they can be very effective when used in conjunction with waste prevention and minimisation strategies upstream of the impoundment.

4.6 Short- and long-term timeframes

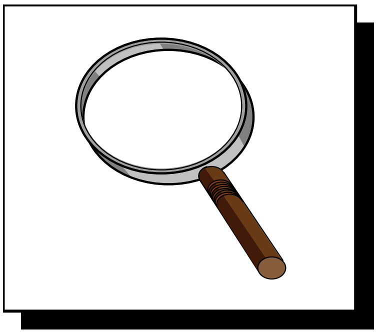
It is frequently the case that only a short-term timeframe is contemplated in an impoundment management strategy. To a certain extent this is understandable since it may be necessary to respond quickly to a water quality problem which manifests itself, particularly if it is highly visible, in the public eye and the source of frequent complaints. A short-term timeframe, however, often goes hand in hand with the use of in-lake management techniques that only address the immediate symptoms and not the causes of the problem. A typical short-term objective may be to reduce excessive algal growth in an impoundment by treating with copper sulphate, or dredging of an impoundment to remove silt. However, such problems can only be prevented by identifying and addressing the sources and causes of the water quality problems and setting long-term objectives to prevent or reduce their impacts. This implies that short-term solutions should go hand-in-hand with long-term management.

Management within a long-term timeframe is particularly appropriate in the case of new impoundments. Although such impoundments may appear to be free from water quality problems initially, an assessment of data from an appropriate water quality monitoring programme may show that the impoundment could start experiencing problems within a few years. Long-term objectives should be set and steps taken from the outset, at the design stage, to prevent the problems from occurring.

4.7 Downstream impacts

It must be recognised that urban impoundment management should not only consider the upstream catchment of the impoundment but also the downstream catchment. In particular, it is necessary to identify downstream users and their requirements, and whether these could be negatively affected by the management strategies implemented to address water quality problems in an impoundment.

An example of a potential downstream impact might be the escape of fish introduced into an impoundment to combat water plant infestations. These fish could upset the ecological balance of downstream aquatic ecosystems and detrimentally affect downstream fishing activities.



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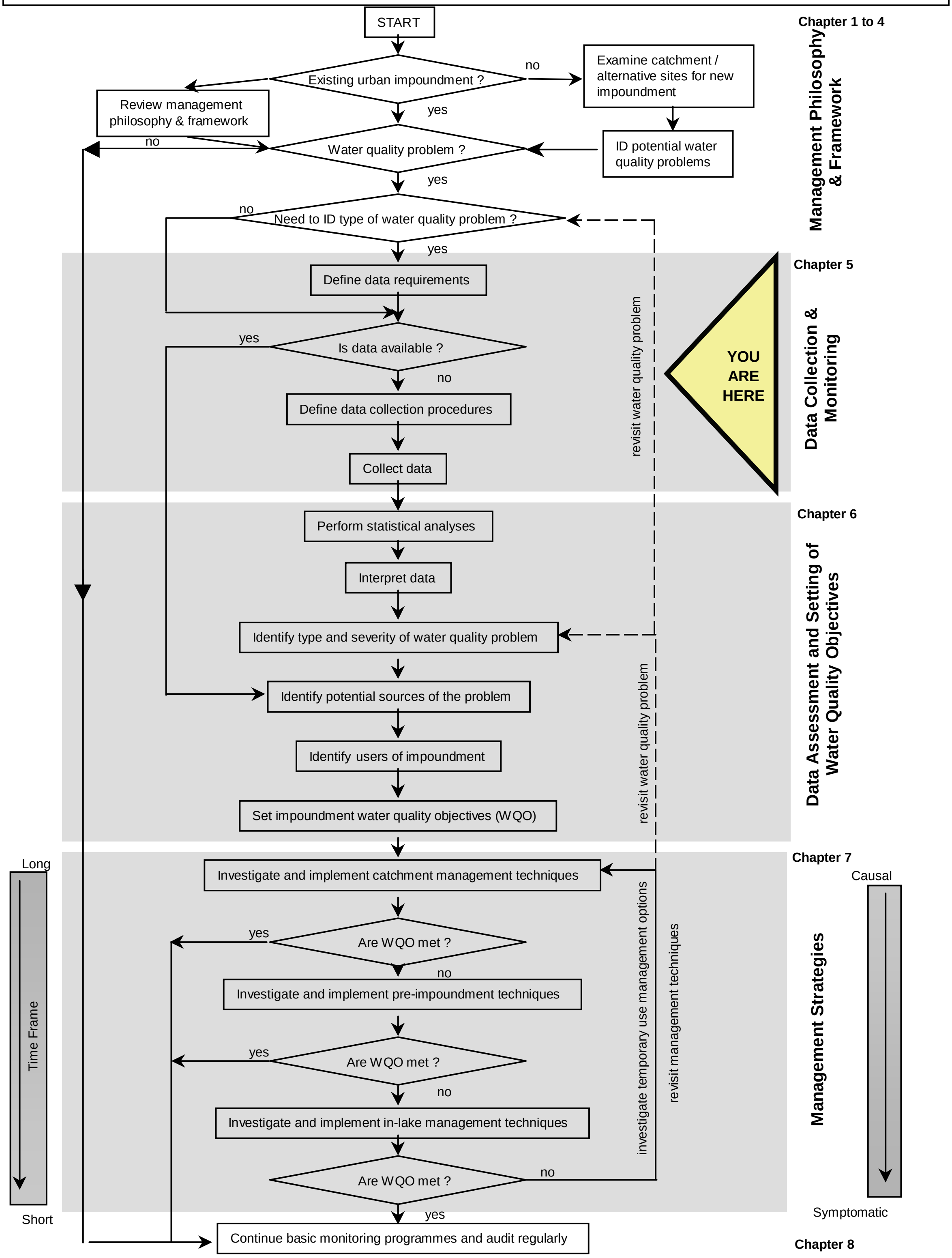


CHAPTER 5: DATA COLLECTION AND WATER QUALITY MONITORING OF URBAN IMPOUNDMENTS

5.1 Introduction

In order to select the most suitable management strategies and techniques to address water quality problems in urban impoundments, it is essential to acquire an understanding of the source, nature, severity and extent of the problems being experienced. To do this, a database must be established containing information about the impoundment and its catchment including comprehensive water quality data sourced from a water quality monitoring programme. If the expertise for designing and implementing a monitoring programme does not exist within the local authority, it is strongly recommended that an agency or person(s) skilled in the science (a water chemist or limnologist) is consulted.

5.2 Basic data

Before instituting a monitoring programme it is important to collect all other relevant information pertaining to the impoundment and its catchment. This should include:

- physical characteristics of the impoundment (e.g. size, depth, surface area, volume);
- flow of water through the impoundment at different times of the year;
- biological features (e.g. reedbeds / fish);
- local climate data;
- characteristics and activities in the catchment (especially land use); and
- activities for which the impoundment is used.

The value of an appropriately designed programme of data collection cannot be over-emphasised as it forms the platform on which any management strategy is devised. The acquisition of relevant information should preferably start before an impoundment is designed and constructed, as the information from a data collection exercise and a water quality monitoring programme within the existing drainage system will give an indication of the potential water quality problems that an impoundment might experience once constructed. It also sets the baseline against which future changes can be evaluated. The impoundment can then be designed in such a way as to minimise or prevent these potential problems.

5.3 Water quality monitoring

In the case of existing impoundments, it will be necessary to deal with any water quality problems retrospectively. The same basic information as described above, however, would still need to be collected and analysed.

Regular water quality monitoring at various points in an impoundment and its catchment (including downstream of the impoundment) will provide valuable information on the behaviour of the impoundment, as well as the source and severity of any water quality problems experienced. Pro-active steps can then be taken to prevent or minimise the problems, preferably before they become too extensive. Regular water quality monitoring is also essential to determine the effectiveness of any management strategy employed. This requires water quality data on the condition of the impoundment prior to the implementation of any management techniques, so that there is a basis against which the effectiveness of the treatment can be evaluated.

Data collection and analysis, particularly water quality sampling, can be expensive. It is important to site water quality sampling points so that optimum information can be gained from the monitoring programme, as well as ensuring that the correct variables are analysed for. Without careful consideration of these aspects, it is possible to collect a large amount of data at great cost that is not very meaningful. Therefore, the location and relative importance of various point and diffuse waste sources that contribute to the flow into an impoundment should first be established, followed by an assessment of the contribution to flow of streams in the catchment, or those directly entering the impoundment. Where there are known point waste sources such as industries or wastewater treatment works, sampling should be conducted upstream and downstream of the discharge point to determine the relative importance and impact of the waste stream (Ward *et al.*, 1990).

Before instituting a sampling programme, the local authority managing an urban impoundment should investigate what sampling is already being carried out in the vicinity. This would include any sampling done by the local authority itself as well as by neighbouring authorities. DWAF has an extensive national sampling programme, whilst most water boards such as Rand Water and Umgeni Water also conduct regular sampling. The local sampling programme established for the impoundment should complement and supplement existing sampling programmes as this will avoid duplication. Before water samples are sent to a commercial laboratory for analysis, enquiries should be made as to whether any department or body within the local authority can assist with sample analysis - most wastewater treatment works have some water quality analytical facilities. This could also assist in containing costs. Local universities, technikons and other academic institutions may also be interested in undertaking research projects on impoundments, thereby providing valuable resources and manpower. University departments that may be interested would include the departments of environmental science, civil engineering, urban planning and development, and possibly architecture. A list of organisations that can be approached to assist with water quality sampling, is given in Chapter 8.

If various institutions are involved in the collection and analysis of samples, it is important to standardise the analytical procedures, otherwise the discrepancy in results due to the different analysis methods may render interpretation of the results difficult. It is suggested that the methods used by DWAF, which are easily accessible, be used (DWAF, 1992).

5.4 Key water quality variables

In all instances there is a basic suite of water quality variables (see Table 5.1) which need to be analysed for, since these provide a general picture of water quality and are generic in identifying the most common water quality problems encountered in South African urban impoundments.

Table 5.1 : Basic Suite of Water Quality Variables Requiring Analysis

Variable	Reason
Flows for all major streams and waste sources	It allows the impoundment manager to quantify the volumes of water originating from each of the main streams and waste sources in the catchment, as well as those entering and exiting the impoundment.
pH	It provides an indication of the acid/alkaline balance of the water in the impoundment and in the inflowing streams.
Electrical conductivity	It provides an indication of the salinity of the inflowing streams and thus the potential to identify significant sources of waste.
Nitrates and phosphates	These nutrients are generally the key factors governing algal and aquatic plant growth and can thus provide an indication of the potential of the impoundment to eutrophy.
Suspended solids	It provides an indication of the amount of sediment in the water and thus the amount that can potentially be deposited in an impoundment.
Faecal coliforms	It provides an indication of the level of bacteriological contamination in the water.
Visual observations	Poor aesthetics (algal scums, malodours and litter) indicate the presence of an underlying water quality problem.

Dissolved oxygen (DO) and temperature would also be valuable water quality variables to include in the basic monitoring programme, but in practice few local authorities have ready access to the required equipment.

The analytical results for each of the generic variables mentioned in Table 5.1 can provide an indication of the presence of one or more common water quality problems within the impoundment and its catchment. In very broad terms, potential problems may become manifest as follows:

- dissolved phosphate levels greater than 0.05 mg/ℓ **could** result in eutrophication-related problems;
- suspended sediment measurements greater than 25 mg/ℓ **could** lead to sedimentation problems;
- faecal coliform counts greater than 150 counts/100 mℓ **could** lead to health-related impacts for full contact watersport recreation;
- flow, pH and electrical conductivity measurements provide a general indication of water quality and the **relative** contribution of contaminants in all incoming streams, including waste streams; and
- poor aesthetics **can** act as a signal to the presence of the underlying water quality problems of eutrophication, sedimentation and bacterial contamination, or their potential to develop.

It should be remembered, however, that the site-specific nature of an impoundment and its catchment may result in the manifestation of problems at different intensities (or different concentration ranges) depending on the particular circumstances at the impoundment.

Based on an interpretation of the results for each of the above variables over a reasonable length of time (e.g. a year to cover seasonal variation), and at more than one point in the impoundment, a preliminary identification of a water quality problem can be made. The next step is to further define the water quality problem (using the SA Water Quality Guidelines (DWAF, 1996)), determine its potential sources and identify which user groups are most affected (Chapter 6).

5.5 In-depth analysis

It may be necessary at this stage, however, to enlist the services of a specialist (water chemist or limnologist) to further examine a specific water quality problem and to carry out further data collection and analysis. This may be particularly appropriate in a complex catchment which contains many waste generators whose waste streams may combine to complicate water quality analysis.

More in-depth analysis of common water quality problems could include the following variables:

- eutrophication - total phosphate, ortho-phosphate, free and saline ammonia, nitrate/nitrite, chlorophyll *a*, algal identification, dissolved oxygen, pH, water temperature, electrical conductivity, turbidity, iron and manganese, stream flows, water clarity (Secchi disk depth);
- sedimentation - total suspended solids, turbidity, water temperature, stream flows, water depth;
- bacteriological contamination - Faecal (F) coliforms, *E. coli*, F. coliphages, F. streptococci, *Cryptosporidium* sp., *Giardia* sp., water temperature, pH; and
- aesthetics - colour, odour, floating matter and litter, water clarity.

The potential sources of contamination resulting in common water quality problems are manifold but tend to be site specific. The results of the monitoring programme together with an examination of land use and waste sources in the catchment will assist in identifying these sources.

DATA COLLECTION AND MONITORING : CASE STUDY LESSONS

We have described in this Chapter, the steps which should be followed in defining your information and data requirements and how to go about collecting the required data. Lets take a look at one of our case study impoundments (see Appendix A) as an example, namely Jan Smuts Dam in Brakpan.

The study team began its investigations of the water quality problems experienced at Jan Smuts Dam by assembling existing information on the impoundment's physical characteristics, flow patterns, monitoring stations, water quality analyses and sampling frequency. Amendments and additions to the collection of this base data were then made in order to obtain a more comprehensive picture of the impoundment.

- **Base Information and Flow**

The existing base line information which was collected at the start of the project is presented below.

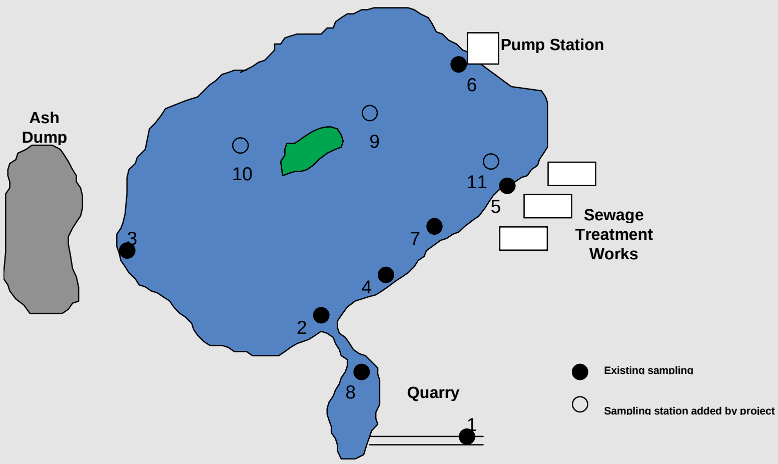
Parameter	Value
Area	70 ha
Volume	810 000 m^3
Mean depth	1.2 m
Source water	stormwater runoff and treated sewage effluent
Catchment type	50 % residential
	20 % commercial
	20 % park land
	10 % industrial
Impoundment use	recreation (intermediate contact)
	stormwater control
	receiving body for treated sewage effluent
Climate	Highveld zone – Mean Annual Precipitation 500-900 mm

The above information was supplemented by a detailed survey of the impoundment which included cross-sections and depth measurements in order to allow for the determination of approximate flows entering and leaving the impoundment.

- **Sampling Stations and Water Quality Variables**

The existing sampling station network (see map on facing page) was quite comprehensive at Jan Smuts Dam. There was a total of 8 sampling stations around the impoundment, which included coverage of the two main inflows (stormwater runoff and discharge from sewage treatment works) and the outflow (Jan Smuts Dam is in fact a natural pan with no outflow, but water is pumped out to a nearby catchment in times of high flow). No sampling stations are located within the catchment because the stormwater network is small and underground. The project team added three further sampling stations, all located within the main body of the impoundment. This was done in order to better evaluate the management strategies in place at the impoundment.

Jan Smuts Dam, Brakpan



Brakpan have historically analysed their water samples for a range of chemical parameters (including pH, electrical conductivity, TDS, alkalinity, chlorides, ammonia, nitrate, orthophosphate, suspended and settling solids and dissolved oxygen) and bacteriological parameters (*E. coli*). The project team increased the parameters to be analysed to include chlorophyll *a*, algal ID, total phosphate, and Kjeldahl nitrogen. This was done to get a better indication of the eutrophication problem. No change was made to the bacteriological parameters.

The existing frequency of monthly sampling was increased temporarily to fortnightly to get a larger dataset and to acquire a better understanding of the functioning of the dam.

Lessons Learnt

- The collection of accurate flow data is a perennial problem for managers because of unfavourable terrain, the equipment required and the costs involved. However, flow data is essential in helping to quantify a water quality problem in an impoundment. The impoundment manager, therefore, needs to trade off the accuracy of flow data against the costs of installing sophisticated flow measuring equipment. Cheap, rough and ready measurements (as carried out at Jan Smuts Dam) may not be ideal, but are essential as a first base.

- Sampling programmes should not be static and need to be reviewed on a continuous basis. This includes review of the water quality variables analysed, the frequency of sampling and the sampling site location. Sample results also need to be reviewed continuously to identify suspect or unusual data. Regular reviews of the effectiveness of a sampling programme help save costs and focus impoundment management.

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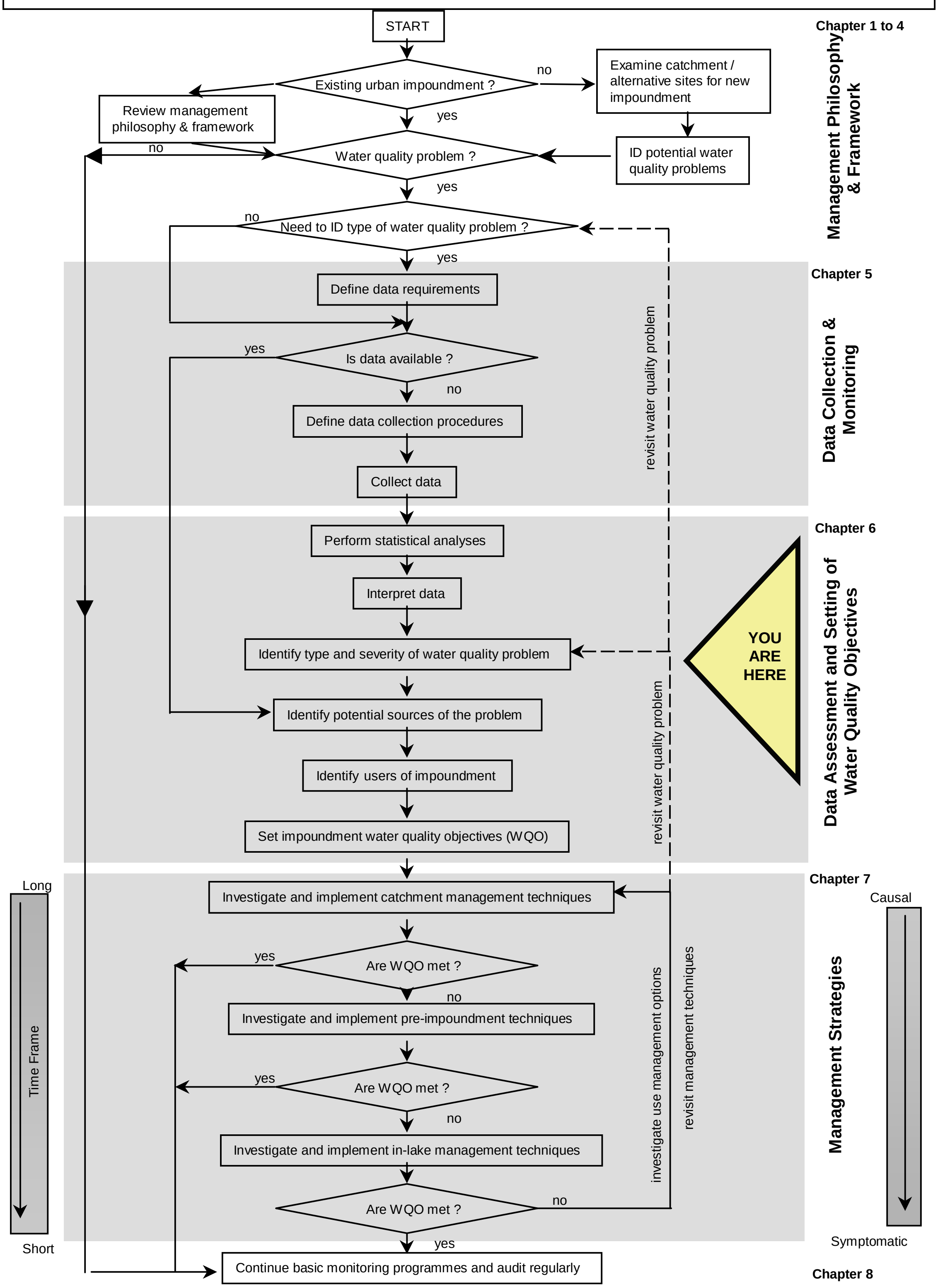

CHAPTER 6: ASSESSMENT OF WATER QUALITY DATA AND URBAN IMPOUNDMENT PROBLEMS

6.1 Data assessment

Accurate and reliable information is a cornerstone of effective management. It is therefore vitally important that in the design and implementation of a water quality monitoring system, the information gathering and assessment procedure is appropriate to the management needs. The monitoring programme must ensure that the right kinds of information are collected, processed, analysed and presented in a way that allows the success or failure of a particular action or decision to be objectively evaluated. Based on the monitoring results, timely decisions can then be taken, if required, on the choice of any corrective actions that might be needed.

The basic data requirements for the assessment of typical water quality problems encountered in urban impoundments have been described in the previous Chapter.

Once the data has been collected, it needs to be manipulated in order to identify potential problem areas and thus to decide on the most appropriate management strategy. The overall objective of data assessment is to enable a local authority to manage its impoundments in such a way as to attain water quality which is "fit for use" for all legitimate users.

Water quality data is typically analysed in a number of ways (Harris *et al.*, 1992; Gilbert, 1987):

- time-series plots of the data provide an indication of the influence of external factors, such as climate, on the water quality in an impoundment, as well as seasonality, long term cycles and other trends;
- summary statistics such as the mean, minimum, maximum, median, 95^{th} percentile and standard deviation values for particular parameters provide an overview of water quality data; whilst
- more sophisticated data assessment techniques such as regression analysis and mathematical modelling allow for more in-depth investigations of a data set.

Each of the above data assessment approaches assists the impoundment manager in tracking the trends in water quality, in identifying the onset of potential problems, as well as determining their potential causes. Graphic presentations of data which show measured water quality conditions against water quality guidelines and objectives (see Sections 6.6 - 6.9) are useful tools to integrate and display data.

As detailed earlier in the Manual (Chapter 2), the potential water quality problems which most commonly face the impoundment manager in South

Africa include:

- eutrophication;
- sedimentation;
- bacteriological contamination;
- aesthetics; and
- serious pollution events.

Some examples of how the data assessment techniques described above can be used in analysing these particular water quality problems are briefly outlined below. It should be remembered that in complex catchments where various water quality problems may manifest themselves in an urban impoundment, the assistance of a specialist (water chemist) may be required to manipulate and assess the data.

6.2 Eutrophication

Measurement of the concentrations of nitrogen and phosphorus compounds in water can be used as an indirect indication that conditions are present that may permit the growth of excess algal and plant biomass. It is useful to track the concentrations of these nutrients on an ongoing basis by way of time-series plots. Excess nutrients, however, are not a problem on their own. Eutrophication is of concern only in that it can result in excess plant growth which in turn creates problems for water users. Relationships between key nutrients and chlorophyll *a* concentrations may need to be developed using more sophisticated data assessment techniques. This allows for an assessment of the level of algal infestation that could arise from specific nutrient concentrations. Algal species identification will indicate the presence of problem algal species.

6.3 Sedimentation

Analysing suspended sediment data, along with the volumes of water entering and leaving an impoundment as well as the volume of water in the impoundment itself, will allow the impoundment manager to determine the level of retention of sediment in an impoundment. A sediment balance can then be calculated and this can be used to predict the approximate time required before the onset of problem conditions.

The sediment balance for an impoundment is best analysed using time-series plots which indicate annual and seasonal trends in the data. This can involve complex calculations requiring accurate flow data and an understanding of sediment movements within the impoundment. A simpler but less precise method is to measure the depth of the water and the sediment in the impoundment over time.

The problem of sedimentation is also of importance in impoundments because of aesthetic considerations and because pathogenic organisms and plant nutrients can be bound to sediment particles. It is frequently necessary, therefore, to relate suspended sediment data to other data for key water quality parameters. By developing these relationships, explanations can be sought for the occurrence or absence of other common water quality problems.

6.4

Time-series trends are frequently used to assess the levels of

Bacteriological contamination

bacteriological contamination in an urban impoundment. These trends will indicate problem times (which may be associated with rainfall events), whilst actual values and summary statistical data will determine whether the levels are significant or not. Testing for changes in bacteriological levels over space and time may also help to isolate the possible sources of contamination.

6.5
Aesthetics

Poor aesthetics are commonly associated with the aforementioned underlying water quality problems. More direct measures, however, have been developed to assess aesthetics. In certain local authorities, regular questionnaires are completed by visitors to impoundments and surrounding parks, which can help the authority to decide on what measures should be implemented to address poor aesthetics. Alternatively, DWAF has developed a rating scale (DWAF, 1994) which, although subjective, provides an indication of the aesthetic quality of an impoundment by assessing the colour and odour of the water as well as the presence of litter.

6.6
Serious pollution events

When assessing the consequences of a serious pollution event, it is important to collect sufficient data concerning the nature of the event, including the type of waste involved, the volume released, and the chemical nature of the waste, so that the initial short-term and the potential long-term impacts can be quantified and monitored in the future. This will aid in determining whether any residual impact can be expected to occur.

6.7
User groups

Once the data from a water quality monitoring programme has been assessed and the nature of any water quality problems identified and understood, water quality objectives need to be set. Water quality can only be described in the context of what the water is or will be used for (DWAF, 1995). In order to set realistic water quality objectives for an urban impoundment, therefore, fitness-for-use criteria for various users of the impoundment should be evaluated.

The recognised user groups as determined by DWAF (1993; 1996) are:

- domestic;
- recreation;
- industry;
- agriculture; and
- the natural environment.

For urban impoundments the main user groups usually are recreation and the natural environment. This is not to say that the other user groups may not also be important depending on the local context, but rather that domestic and industrial use of water generally undergoes some form of treatment in an urban area prior to use, whilst in the context of urban impoundments, use for agriculture is limited (e.g. frequently confined to the irrigation of surrounding park land and sports grounds).

6.8
Water quality guidelines

DWAF has prepared water quality target guidelines for all the recognised user groups (DWAF, 1993; 1996). These guidelines act as a decision support tool on the water quality requirements of each user group. They are updated and expanded upon from time to time, therefore the impoundment manager should confirm that they are using the most current version. The water quality guidelines should be used unless there are specific reasons why they are not applicable. In certain cases, such as an impoundment, the development of site-specific guidelines may be required, particularly if a guideline is not available for a specific variable of concern. Summaries of the water quality guidelines for the key user groups at urban impoundments (recreation and the natural environment, i.e. aquatic ecosystems) are given in Tables 6.1 and 6.2. More detailed information and explanations are provided in DWAF's Water Quality Guideline series of documents (DWAF, 1993; 1996).

It is highly unlikely that a local authority will test water samples for all the constituents listed in Tables 6.1 and 6.2. Instead, key variables will be selected depending on the nature of the water quality problem being investigated (see Chapter 5).

6.9
Setting water quality objectives

The setting of water quality objectives is important because this provides the standard or benchmark against which the management of the urban impoundment can be assessed. Therefore, the water quality objectives which are set need to be both realistic and achievable for the local circumstances.

DWAF is currently developing water quality objectives for all catchments in South Africa on a systematic basis. The impoundment manager, therefore, should contact the regional DWAF office to establish whether water quality objectives for the catchment in which an impoundment is situated have been set.

As a first round, the objectives for an impoundment can be set to those of the DWAF guidelines. However, it may be necessary to review these values on a site-specific basis particularly in regard to how water quality constituents relate to each other. Thus a particular user group may have a strict guideline for a specific water constituent, yet a decision may be taken that the impoundment be managed to a less stringent value. For example, the chlorophyll *a* guideline value for full contact recreation is <15 μg/ℓ. However, should some other factor (e.g. suspended sediment and light penetration) be limiting plant growth in the impoundment, a less stringent objective may be more realistic. In the case of Hennops Lake, Centurion, the level of suspended sediment is high which reduces the depth of light penetration into the water, which, in turn, results in a low algal standing crop. In the event, however, of a reduction in the suspended sediment load entering the impoundment, with a corresponding increase in light penetration, nuisance levels of algal growth can be expected which would require a review of the target objective for chlorophyll *a*.

Table 6.1 : Summary of DWAF Water Quality Guidelines for Recreation

Water Quality Constituent	Target Guideline Range
Algae	**Contact recreation** Free-floating algae: 0 - 15µg/ℓ (mean concentration) Blue green algae : 0 - 6 counts (see guideline document for detail) Attached filamentous algae: should be absent **Intermediate contact recreation** See guideline document for detail **Non-contact recreation** Free-floating algae: 0-20 µg/ℓ (mean concentration) Attached filamentous algae: should be absent
Nuisance plants	No numerical guideline proposed.
PH	**Full contact/intermediate contact recreation** pH 6.5 - 8.5 **Non-contact recreation** Not relevant.
Faecal coliforms / *E. coli*	**Full-contact recreation** Faecal coliforms: 0 – 150 counts/100 ml *E. coli*: 0 - 130 counts/100 mℓ **Intermediate contact recreation** Faecal coliforms: 0 - 1 000 counts/100 mℓ *E. coli*: Use the guidelines for faecal coliforms **Non-contact recreation** Not relevant.
Faecal Streptococci	**Full-contact recreation** 0 - 30 counts / 100 mℓ **Intermediate contact recreation** 0- 230 counts/100 mℓ **Non-contact recreation** Not relevant.
Enteric viruses	**Full-contact/intermediate contact recreation** 0 (TCID ^{50}/10 l) **Non-contact recreation** Not relevant.
Bilharzia (schistosomiasis)	**Full-contact/intermediate contact recreation** No snails capable of acting as the intermediate host of the bilharzia parasite should be present **Non-contact recreation** Not relevant.
Protozoan parasites	**Full-contact/intermediate contact recreation** <1 *Giardia* cyst/10 ℓ and <1 *Cryptosporidium* 00 cyst/10 l **Non-contact recreation** Not relevant.
Coliphages	**Full-contact/intermediate contact reaction** Coliphages: 0 - 20 counts/ mℓ **Non-contact recreation** Not relevant.
Chemical irritants	No numerical guideline proposed.
Clarity	**Full-contact/intermediate contact recreation** > 3.0 Secchi disk depth (m) **Non-contact recreation** See guideline document for detail
Odour	Recreational waters should be free of any substances which cause noticeably unpleasant or objectionable odours
Floating matter	No numerical guideline proposed.

Table 6.2 : Summary of DWAF Water Quality Guidelines for Aquatic Ecosystems

Water Quality Constituents	Conditions	Format	TWQR *	Unit
Un-ionised Aluminium	pH < 6.5	Acid-soluble	0 - 5.0	μg/ℓ
Un-ionised Aluminium	pH > 6.5	Acid-soluble	0 - 10.0	μg/ℓ
Ammonia-N		Un-ionised	0 - 7.0	μgN/ℓ
Arsenic		Total	0 - 10.0	μg/ℓ
Atrazine			0 - 10.0	μg/ℓ
Cadmium	Conc. of $CaCO_3$/ℓ	Total		
Cadmium	< 60	Total	0 - 0.15	μg/ℓ
Cadmium	60 - 119	Total	0 - 0.25	μg/ℓ
Cadmium	120 - 180	Total	0 - 0.35	μg/ℓ
Cadmium	> 180	Total	0 - 0.40	μg/ℓ
Cadmium (cold water fish)	Conc. of $CaCO_3$/ℓ			
Cadmium (cold water fish)	< 60		0 - 0.07	μg/ℓ
Cadmium (cold water fish)	60 - 119		0 - 0.10	μg/ℓ
Cadmium (cold water fish)	120 - 180		0 - 0.15	μg/ℓ
Cadmium (cold water fish)	> 180		0 - 0.17	μg/ℓ
Chlorine		Total residual	0 - 0.20	μg/ℓ
Chromium (III)		Dissolved	0 - 12	μg/ℓ
Chromium(VI)		Dissolved	0 - 7	μg/ℓ
Copper	Conc. of $CaCO_3$/ℓ	Dissolved		
Copper	< 60	Dissolved	0 - 0.30	μg/ℓ
Copper	60 - 119	Dissolved	0 - 0.80	μg/ℓ
Copper	120 - 180	Dissolved	0 - 1.20	μg/ℓ
Copper	> 180	Dissolved	0 - 1.40	μg/ℓ
Cyanide		Free cyanide	0 - 1.0	μg/ℓ
Dissolved Oxygen			80 - 120	% of saturation
Endosulfan			0 - 0.01	μg/ℓ
Fluoride		Dissolved	0 - 750	μg/ℓ
Iron	No more than 10% of background dissolved iron concentrations			
Lead	Conc. of $CaCO_3$/ℓ	Dissolved		
Lead	< 60	Dissolved	0 - 0.2	μg/ℓ
Lead	60 - 119	Dissolved	0 - 0.5	μg/ℓ
Lead	120 - 180	Dissolved	0 - 1.0	μg/ℓ
Lead	> 180	Dissolved	0 - 1.2	μg/ℓ
Manganese		Dissolved	0 - 180	μg/ℓ
Mercury		Total	0 - 0.04	μg/ℓ
Nitrogen (Inorganic)	Surface water inorganic N < 15% under unimpacted conditions			
pH	pH vary no more than pH 0.5 or 5%			
Phenols			0 - 30	μg/ℓ
Phosphorus (Inorganic)	Surface water inorganic P < 15% under unimpacted conditions			
Selenium		Total	0 - 2	μg/ℓ
Temperature	Daily water temp. not vary > 2^{o}C or 10% over normal daily variation			
Total Dissolved Salts/Solids	No more than 15% from normal cycles of water body and amplitude and frequency of natural cycles should not be changed			
Total Suspended Solids			0 - 100	mg/ℓ
Zinc		Dissolved	0 - 2	μg/ℓ

*** TWQR = Target Water Quality Guideline**

The water quality objectives which are set for an impoundment should also be realistic in terms of the catchment as a whole. For example, an *E. coli* target objective of 130 counts/100 mℓ (which permits full contact recreation) may not be attainable in a lake or dam if there is an un-sewered informal housing development immediately upstream of the impoundment.

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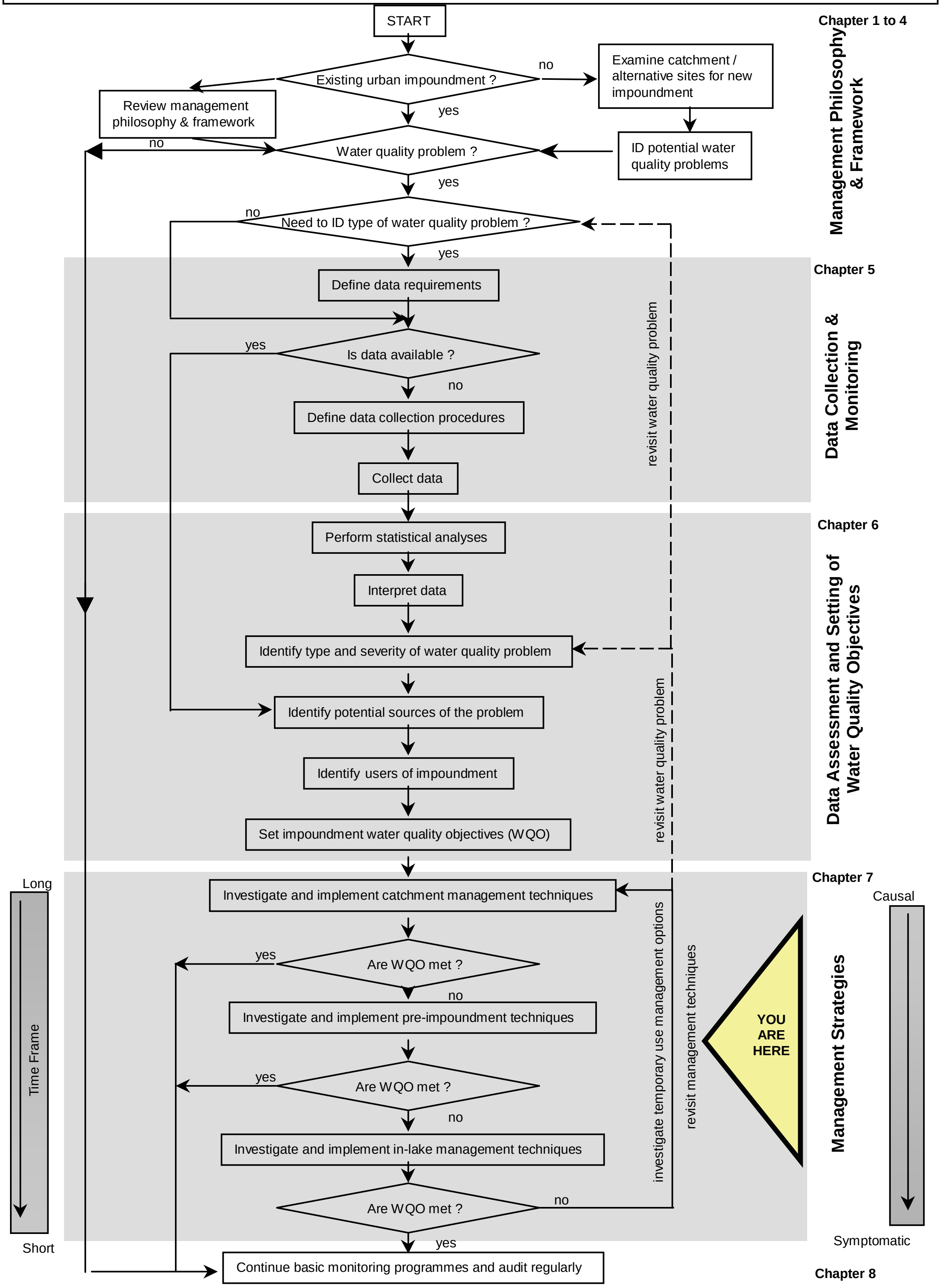


CHAPTER 7: URBAN IMPOUNDMENT MANAGEMENT TECHNIQUES

7.1 Introduction

Once the basic information and water quality data for an impoundment have been collected and analysed, and the water quality objectives have been set, a management strategy can be formulated to meet the objectives. This may involve the use of one or more management techniques.

In this Chapter, a brief outline is given on the approach to catchment management, whilst specific techniques which can be used for pre-impoundment management and in-lake management are described.

7.2 Catchment management

In essence the focus of catchment management is on controlling point and non-point sources of pollution or waste and thus addressing the waste production and delivery elements of the management hierarchy (i.e. the causes of water quality problems). The beneficial effects of management strategies and control measures introduced at a catchment level will normally require time to plan and implement and therefore will only be felt over the long term. Current approaches to catchment management are summarised below whilst more detail is provided in Appendix B.

7.3 Point source waste management

In South Africa, the Uniform Effluent Standards (UES) have been in place for over 20 years (V. d. Merwe and Grobler, 1990). The UES approach aims to regulate the input of wastes or effluents into river systems by way of uniform standards. The net goal is to approach zero discharge of effluents. These standards were set to treat contaminated effluents on the basis of BATNEEC (best available technology not entailing excessive cost).

This approach, however, has a number of drawbacks (V. d. Merwe and Grobler, 1990). The prime focus is on the effluent and not on the receiving water. This ignores the fact that there may be more than one discharge to a river, or that there may be high natural background concentrations of a particular constituent already in the river system. Also, the ability of the river system to assimilate wastes is not brought into the equation. On the plus side, however, the approach is relatively simple, comprehensible and straightforward in application.

Although the application of the UES in South Africa has ultimately led to a decrease in the rate of water quality deterioration (V. d. Merwe and Grobler, 1990), deterioration of the water resource has continued. It was realised that a different more advanced approach to water quality management was required. In the early 1990s, DWAF adapted its approach to one where the following principles would be included:

- " Because water is such a scarce resource, effluent has to be returned and re-used in order to help balance water supply with the demand for water. Water quality at pristine unaffected levels therefore cannot be maintained and some changes in water quality are accepted as being inevitable.

- Waste disposal to air or soil (e.g. effluent irrigation, dumping of mining wastes or gaseous emissions) impacts on the quality of surface and groundwater. Therefore, waste disposal has to be evaluated holistically and the best practical environmental option has to be selected.
- Economic development should not take place at the expense of the environment, nor should it make excessive demands on the natural resource base. Sustainable economic development which is in balance with environmental protection and sustainable resource use is encouraged.
- The desired quality of a water resource is determined by its present and/or intended uses. This quality should be stated as a list of water quality objectives agreed to by all water users.
- It is accepted that the water environment has a certain, usually quantifiable, capacity to assimilate pollutants without detriment to predetermined quality objectives.
- The assimilative capacity of a water body is part of the water resource and, as such, must be managed judiciously and shared in an equitable manner amongst all water users for the disposal of their wastes.
- For those pollutants which pose the greatest threat to the environment, because of their toxicity, extent of bio-accumulation and persistence, a precautionary approach aimed at minimising or preventing inputs to the water environment should be adopted. " (V. d. Merwe and Grobler, 1990; DWAF, 1995).

DWAF’s new approach includes both the principles of Receiving Water Quality Objectives (RWQO) to non hazardous wastes, and pollution prevention for hazardous substances.

At provincial and local authority level, mechanisms can also be employed to control waste streams. These mechanisms include ordinances and by-laws, levies and penalties, as well as planning regulations. For example, a private company in Gauteng presently pays an estimated R120 000/a to their local authority in the form of a levy on their discharged effluent. This cost is determined by both the volume of effluent discharged and the chemical oxygen demand (COD) concentration of the effluent. As a result, the company recently instituted a water usage rationalisation programme which has resulted in significant cost savings in terms of fresh water intake and effluent volume discharged.

It can be seen, therefore, that the control of point source waste can be managed via the use of regulations, by-laws and permits. In this way, adoption of the “polluter pays” principle also helps focus attention on the production of waste and, in turn, on its prevention or reduction. Monitoring of wastes and effluents, however, becomes an important factor in this process. Monitoring programmes are used to gather information on waste streams and on river water quality, on how changes take place over space and time and on how water quality responds to management actions.

Problems can however be expected in the enforcement of regulations and permit requirements. Options available to improve enforcement, range from more policeing to inviting all members of an affected community to participate in the management of the system, thereby employing a degree of self-regulation.

7.4
Diffuse source waste management

Non-point or diffuse source waste management is more difficult to apply, particularly in urban areas. The traditional design of urban stormwater systems provides for the rapid removal of stormwater via pipes and canals to, ultimately, a river reach (Ellis, 1989). This results in sometimes considerable, albeit transient, waste loads entering the system. Typically, high concentrations of sediments and nutrients, oils, grease, litter and other wastes, enter the stormwater system. In many South African cities, burst or overflowing sewers are presently a common source of diffuse pollution. The net result is that any storage system downstream, such as an urban impoundment, will act as a settling point for these wastes.

The management of diffuse source wastes requires an integrated approach, where the redesign of planning practices, regulations, and educational measures should be viewed as a whole.

Since traditional stormwater systems act as conduits for diffuse source wastes, abatement or source control methods identified in the US have at their core the philosophy of separating clean and dirty water systems. Uncontaminated water is either allowed to recharge groundwater or is discharged to a river system in a controlled manner. All contaminated water, however, is collected, stored and discharged to a sewage treatment works when the works are able to cope with the extra volumes (Smisson, 1990).

Recharge to groundwater systems can be done making use of soakaways in residential properties. Permeable pavements and the use of swales (shallow grass filled ponds) allow water to be routed to either groundwater or surface water systems (Figure 7.1 overleaf).

Contaminated runoff from roads and car parks will need to be treated before discharge. A system of small tanks can be used to store water temporarily for subsequent release to the sewer when flows permit.

While these systems may be inappropriate in existing urban areas, new developments could incorporate such concepts from the outset. In existing areas, a number of strategies can be employed which will reduce waste loads. Such options include:

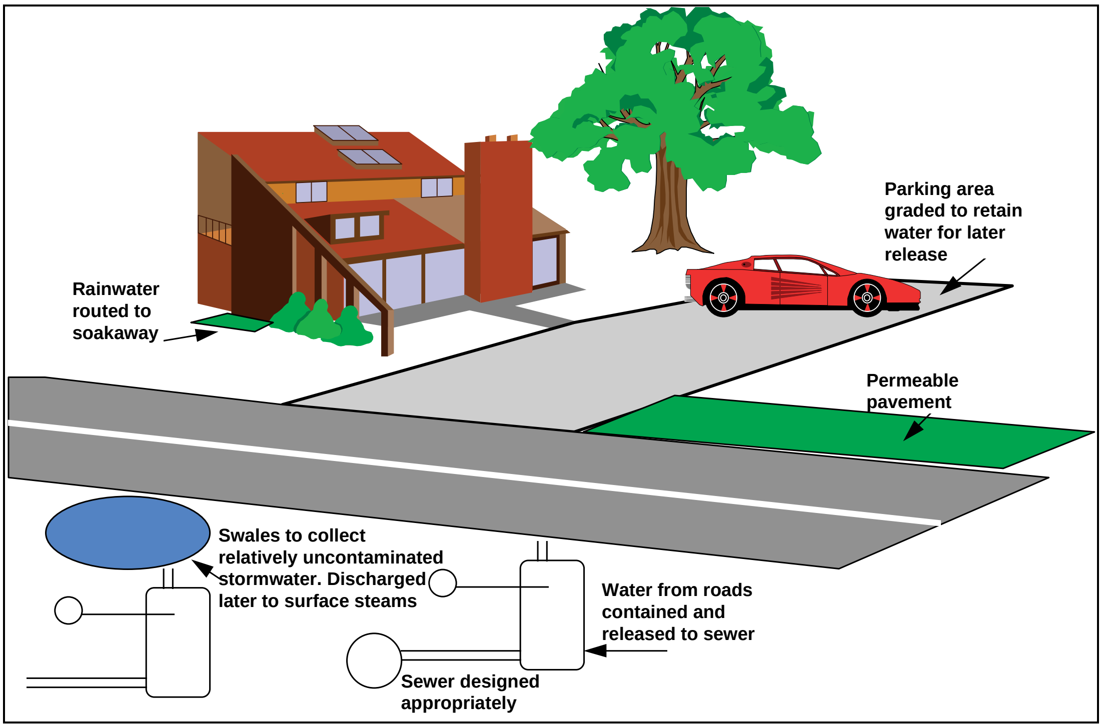


Figure 7.1 : Diffuse Source Waste Control Strategies (after Smisson, 1990)

- Routine cleaning of paved areas - an ongoing routine street-cleaning programme, whereby waste and litter are removed to a proper facility, will reduce the amount of wastes which could find their way into the stormwater system.
- Controlled and regular disposal of household wastes such as paint, solvents, chemicals and oil so that they are not poured down a street drain (Roesner and Hobel, 1992).
- Control of the use of and application of pesticides, herbicides and fertilisers.

Many people residing in urban areas are unaware of where stormwater systems drain. It is often believed that stormwater eventually ends up in a wastewater treatment facility and therefore, that it does no harm to dispose of noxious chemicals down the stormwater drain (Roesner and Hobel, 1992). An education programme is thus a need in both established and new urban communities. It is important to convince people residing in towns and cities that they have some ownership over the stormwater systems in their area and that it ultimately affects them directly if wastes are allowed to enter the system.

This aspect of education is of particular relevance in those areas where informal settlements are developing. The low socio-economic status of a community may mean that there is insufficient motivation for diffuse source waste control. The Reconstruction and Development Programme (RDP) in South Africa may put funds in the hands of these communities, so that source control becomes a viable option, but education on its own can play a key role in reducing waste loads from such areas. Furthermore, the collection and storage of rainwater for use in gardening and urban agriculture, could reduce the load of suspended sediments in the water in those areas where only a rudimentary infrastructure exists.

In terms of reducing the sediment load in stormwater systems in urban areas, a number of aspects can be addressed;

- developers should consider slopes and drainage paths in the design of any new venture, from office developments through to low-cost housing;
- sediment control measures should be implemented at any new development or construction site to retain sediment on the site; and
- soil stabilisation and revegetation practices should be encouraged immediately after construction has been completed.

Should improved planning practices, education and appropriate waste control measures not result in an improvement in stormwater quality, or if there is a reluctance for economic reasons to pursue the concept of diffuse source waste control, regulations will be required to address these issues.

Typically, however, and to the ultimate detriment of stormwater systems, the responsibility for the various aspects which contribute to diffuse waste loads rests in a number of different hands - the cleaning of roads, maybe in one department of a local authority, maintenance of sewer systems in another, waste disposal in yet another, and so on. This makes the overall control of the stormwater system difficult to manage. Additionally, stormwater systems may cross over municipal and regional boundaries.

Permit systems have been employed in the past, but these require enforcement, which places additional strains on restricted funds (Novotny, 1988). However, if any improvement in stormwater control is to be realised, a combination of education, innovative design practices, waste minimisation or re-use, legislation, regulations, permits, and penalties must all be employed in order to reach the end result of improved water quality in river systems. This is particularly apt in relation to catchment management.

7.5 Pre-impoundment management

Pre-impoundment management techniques focus on improving water quality at the points of inflow to an impoundment. They thus address the transport element of the management hierarchy. Although pre-impoundment management techniques only deal with the symptoms of water quality problems and not their causes, they can be usefully applied together with other catchment management techniques. They may also be considered as lower cost solutions to water quality problems. The techniques available to the impoundment manager are briefly summarised on the following pages. More detail is given in Appendix B.

KEY TO INFORMATION PRESENTED IN THE DESCRIPTION OF URBAN IMPOUNDMENT MANAGEMENT TECHNIQUES

The following definitions apply with respect to the terminology used in the descriptions:

Costs
Low cost = management techniques expected to cost < R100 000
Medium cost = management techniques expected to cost < R1 000 000
High cost = management techniques expected to cost > R1 000 000

Timeframe
Short-term = a time period of < two years
Medium-term = a period of two to five years
Long-term = a time period of > five years

The techniques are not presented in any order of preference. No level of confidence is expressed for the techniques because the prevailing conditions at each impoundment are site-specific. However, case study experience with specific impoundment techniques is presented where appropriate.

A. *CHEMICAL CONTROL*

Cost: Medium
Timeframe: Short term

i) Principle

The principle behind the chemical control or dosing of in-flowing water to an impoundment is that of rapid and efficient removal or transformation of contaminants using chemicals.

ii) Typical problems addressed with this strategy

- Chemical dosing can manage excessive nutrient concentrations as well as high levels of bacterial contamination.
- Current work in North America is utilising liquid aluminium sulphate, commonly called alum, to dose water to remove nutrients chemically.
- Chlorination has been used locally as a means to address the bacteriological contamination of in-flowing streams.

Positive aspects	Negative aspects
• Dosing with alum has shown up to an 85% reduction in phosphates; an 80% reduction in metals and a 99% reduction in bacteria. • Alum has also been used extensively to seal/treat lake bottom sediments which contain high levels of nutrients. • Chemical dosing can be beneficial in low-flow situations.	• Adds additional chemical constituents to the river system with potential negative downstream impacts. • Active treatment process which requires constant attention. • High costs and infrastructure.

iii) General comments

- In terms of cost, a plant to dose alum to reduce phosphates, metals and bacteria at Lake Ella (in the US) for 63 000m^3/d would cost R1.5 million and approximately R40 000/a in running costs (Harper and Herr, 1992).
- The resultant concentration of aluminium in the water was found to be 0.044mg/ℓ in the US. The US Environmental Protection Agency guideline for sensitive aquatic species is 0.087mg/ℓ (Harper and Herr, 1992).

LOCAL EXPERIENCE : HENNOPS LAKE, CENTURION (see Appendix A)

Aim of strategy: To reduce the bacteriological contamination of Hennops Lake to a level which would not be detrimental to watersport activities.

Date strategy implemented: May, 1993.

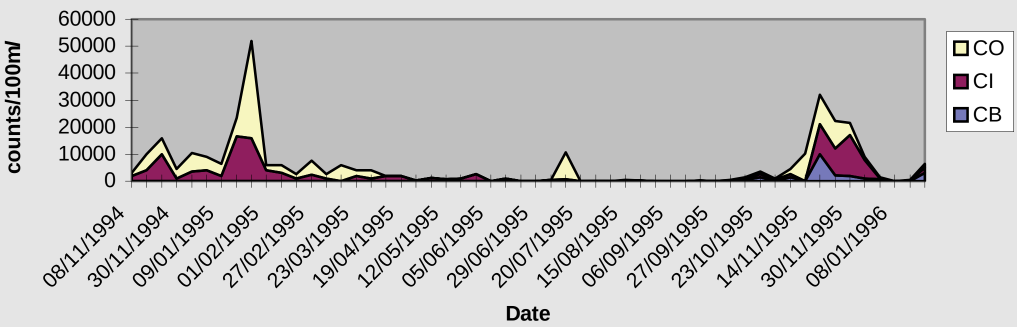
Capital costs: R32 300 for the purchase and installation of a chlorination system. The system includes a 1 ton chlorine drum, a 10 000 g/h chlorinator, a diffuser and associated pipework.

Maintenance costs: Approximately 10 chlorine cylinders are used each year which at a cost of R4 200 per cylinder amounts to R42 000/a. A further R5 000/a is incurred in maintenance costs. This excludes the costs of water usage in the system, so annual maintenance costs can be said to total about R50 000/a.

Evaluation: Chlorination of the inflow occurs during winter only. Thus, any changes as a result of the strategy will only be seen during this time.

The results indicate that significant concentrations of bacteria are present in the upper catchment, and that concentrations are significantly lower at the inflow. The sampling site at the inflow to the Hennops Lake is at the point where the chlorination takes place, and thus localised disinfection appears to be occurring. In order to evaluate the bacteria die-off in the upper reaches of the lake, a series graph is presented for the inflow, outflow and a sampling station approximately 100 m downstream.

F. coliforms at inflow and outflow to Hennops Lake



CO = Outflow; CI = Inflow; CB = Mid-point

This graph shows that during summer, high concentrations of bacteria are found at the inlet and in the lake. In winter these values decrease to levels which are acceptable for recreation during most months.

Lessons Learnt

It would appear as though during winter, chlorination is working, but the technique is not effective during high flows (summer).

B. WETLANDS

Cost: Medium **Timeframe:** Long term

i) Principle

The principle of using wetlands to treat urban runoff is increasingly becoming a more accepted water quality management option. The process is one of utilising nutrients in water to “grow” plants and to create a "natural" ecosystem capable of removing nutrients and trapping sediments upstream of an impoundment.

ii) Typical problems addressed with this strategy

- Wetlands act as a “natural” treatment process to reduce nutrient and sediment concentrations in waters flowing into impoundments.
- There are generally two types of wetland used to control urban runoff:
  - Free water surface wetlands where basins or channels are created and emergent vegetation is grown to absorb nutrients from water as it flows through the system.
  - Sub-surface flow wetlands where a gravel or sand media will support the emergent vegetation. The bed beneath the gravel is sloped and the water is encouraged to move through the gravel layer.

Positive aspects	Negative aspects
• Some wetlands can remove up to 70% of in-flowing phosphates. • 60 - 70% clarification of water can occur. • Utilises natural biological, physical and chemical treatment processes. • Extends the local ecological resource base.	• Large areas are required/m^3 of water to be treated. • Can trap and concentrate sediments and waste with offensive after-effects. • May require periodic harvesting or dredging to remove waste load.

iii) General comments

- Wetlands can be applied on a small scale to treat urban runoff from individual blocks of houses within a suburb.
- Wetland types include reed beds, bogs, marshes and swamps, and thus a whole range of ecosystems can be created.

LOCAL EXPERIENCE : ZOO LAKE, JOHANNESBURG (See Appendix A)

Aim of strategy: To treat the high nutrient content of the washwater from animal cages at the Johannesburg Zoo by settling and filtration through a wetland system.

Date strategy implemented: July/August 1997.

Capital costs: Initial budget (1994) R850 000; sealing of beds 1 and 2 (1997) ± R100 000 (Bed 3 still to be done ± R50 000)

Maintenance costs: None as yet.

Evaluation: Too early to assess.

C. DILUTION/FLUSHING

Cost: High **Timeframe:** Medium term

i) Principle

The technique of dilution/flushing can result in an improvement in water quality within an impoundment by two processes:

- the concentration of contaminants can be reduced; and
- the water exchange rate within the impoundment can be accelerated.

ii) Typical problems addressed with this strategy

- The net effect of dilution is to reduce nutrient levels, thereby lowering the growth rate of algae and other invasive water plants.
- Dilution is frequently used together with flushing as a restoration technique. For dilution (nutrient reduction) to be cost-effective, the inflow water must be substantially lower in nutrient concentrations (i.e. of a better quality) than that of the impoundment.
- For flushing, the rate must be related to the algal growth rate.

Positive aspects	**Negative aspects**
• In North America phosphate reduction has approached 30%. • In-lake chlorophyll *a* levels have decreased by up to 80%. • Blue-green algae become less prevalent.	• Large volumes of low nutrient concentration water are required. • Internal nutrient loading from sediment and biota may result in recovery only over a longer period. • Certain impoundments do not respond because the inflow phosphate concentration is not low enough. • Water for flushing is often not available.

iii) General comments

- In certain impoundments, a continuous low-rate inflow of water is preferable to a high-rate input for a relatively short period.
- The potential for using dilution/flushing as a technique requires careful consideration on a site-specific basis, particularly if a nearby downstream impoundment will receive the contaminated water.

D. DIVERSION

Cost:
Medium to high
Timeframe:
Medium term

i) Principle

The principle behind the diversion of poorer quality water away from impoundments is based on a reduced external waste loading to the impoundment. This technique involves the construction of pipelines, or canals around impoundments to take contaminated water to a point away from the impoundment.

ii) Typical problems addressed with this strategy

- Diversion of contaminated in-flowing water, typically from point sources but also from non-point sources, especially first flush diversions (or first summer rain diversions).

Positive aspects	Negative aspects
• Total phosphate loading can decrease by up to 60%. • Resultant chlorophyll *a* levels in the impoundment can be reduced by up to 75%.	• Impoundments respond slowly so this could be a long-term measure. • Internal loading may be important and so expected effect may not be realised. • Can transfer the problem downstream. • Further treatment of the diverted water may be required.

iii) General comments

- Internal loading becomes more important in shallow impoundments. This is because phosphates can be released more easily from the sediments into the photic zone.
- The main lesson learnt in the Northern Hemisphere is that a holistic approach is required, which does not just divert nutrient-rich water but also addresses the problem at source.
- The important information required includes changes in water quality over time during storm events, so that better quality water is not diverted.

E. DETENTION PONDS

Cost: High **Timeframe:** Long term

i) Principle

Detention ponds are used to trap and/or remove nutrients, bacteria or sediment before they enter the urban impoundment.

ii) Typical problems addressed with this strategy

- High-nutrient, sediment and bacteriological concentrations in in-flowing water

Two main processes occur:

- Biochemical conversion of nutrients from the dissolved to the particulate form through uptake by algae and plants.
- Sedimentation of phytoplankton, bacteria and particulate matter.

Positive aspects	Negative aspects
• Nutrient reduction can be as much as 50%. • Sediment reduction can be as much as 75%. • In a receiving water body, chlorophyll *a* reductions of up to 80% have been noted.	• High capital cost for construction. • Land requirements. • Size of detention pond in relation to inflow is critical.

iii) General comments

- The size of the detention pond should aim at the optimum retention time and not simply at a long retention time.
- The mean depth should not exceed the depth of the photic zone.
- The bottom sediment will have to be removed periodically.

LOCAL EXPERIENCE: ZOO LAKE JOHANNESBURG (see Appendix A)

Aim of strategy : To reduce the sediment load emanating from the stormwater catchment.

Date strategy implemented: Unknown.

Capital costs: Unknown

Maintenance costs: August/September 1994 = R70 000. This was cheap as a pit was dug and silt and sediment buried, therefore no transport was needed (including transport costs = ± R120 000).

Evaluation: Presented below are suspended solids data for the inflow to the detention pond (lakelet) and the outflow to Zoo Lake. It can be seen that there is a slight reduction in the median concentration of suspended sediments within the lakelet. The value decreases from 21.5 mg/ℓ to 18 mg/ℓ. Of particular importance however, is that the maximum value for the outflow is significantly lower than the inflow (376 mg/ℓ inflow, 73 mg/ℓ outflow). Typically the higher load would occur during storm events and the current strategy is to bypass the initial storm events around the main lake by way of an underground canal. This helps to reduce the sediment load to the lake itself. The fact that the lakelet requires periodic dredging and that there is a need to use an aerator to mix in oxygen to the system, means that a portion of the sediment load is also being trapped in the lakelet. The aerator was installed in order to reduce noxious odours from the anaerobic sediments.

Suspended sediment data for the lakelet at Zoo Lake (1995-1996)

	Inflow	**Outflow**
Mean	40.53125	20.5075
Median	21.5	18
Min	0.8	0.4
Max	376	73
95 th	176.4	44.65
Count	80	80

Lessons learnt

In areas where in-flowing river suspended sediment concentrations are high, detention ponds are successful in removing the sediment before it enters the main impoundment.

7.6 In-lake management

In-lake management techniques address only the symptoms of water quality problems. However, they have proved popular with impoundment managers because generally speaking they are low-cost techniques which can produce quick results. Used in tandem with other pre-impoundment and catchment management techniques, they can prove highly effective, but it should be remembered that if used in isolation, they act as short-term measures which do not address the causes of the water quality problem. More detail regarding each of the techniques is given in Appendix B.

F. BIOMANIPULATION

Cost: Medium	Timeframe: Long term

i) Principle

The term 'biomanipulation' has been defined as the management of aquatic communities by controlling natural populations of organisms.

Cost:
Medium

Timeframe:
Long term

ii) Typical problems addressed with this strategy

- Improves water quality by altering the aquatic food chain's use of nutrients.
- Reduces algal populations by preferential selection towards particular fish species.
- Reductions in fish populations favour the larger algae-eating zooplankton species.
- Reductions in bottom feeding fish can reduce turbidity and improve water clarity.

Positive aspects	Negative aspects
• Restructuring of fish populations can lead to increased water clarity and reduced algal growth. • Nutrients are recycled to deeper waters and are thus less available for algal growth.	• May require dramatic reduction in fish to unacceptably low levels. • Certain impoundments may be dominated by large deep-bellied fish which are not suitable for biomanipulation. • Increasing water transparency can lead to macrophyte infestations because of increased light penetration. • Few algae-eating indigenous fish species.

iii) General comments

- The use of biomanipulation may not be appropriate in all impoundments and other strategies (such as fishing) may be preferable. Biomanipulation is site-specific and requires an assessment of the recreational use of the impoundment, as well as of the functioning of the ecosystem.

G. DREDGING TO REMOVE SEDIMENTS

Cost: Medium to High **Timeframe:** Short term

i) Principle

Sediments reduce the effective depth of impoundments and can act as stores for nutrients, thus dredging is aimed at removing the sediment.

ii) Typical problems addressed with this strategy

Sedimentation can result in:

- Silting up of an impoundment which influences recreational activities and fish populations and can encourage dense stands of macrophytes to develop.
- The sediments can store and act as sources of nutrients for algal growth.
- The sediment may accumulate toxic substances which affect other water quality aspects of the impoundment.

In shallow impoundments the release of sedimentary phosphorus may be significant. Phosphates may be derived from two principal sources:

- Chemically bound to the in-flowing sediment itself which settles out in the impoundment.
- Bound in the biological populations which, on death, settle on the bottom of the impoundment.

Positive aspects	Negative aspects
• Removes sediments and nutrients. • Removes cysts, spores, autospores, resting cells of algae and other organisms. • Reduces algal populations and in some cases shifts species away from the green algae.	• Land is required to dispose of sediment. • Sediment may contain toxic materials. • Water from the settled sediment may need to be treated prior to discharge back to the impoundment.

iii) General comments

- Testing and classification of the sediment are required, since it may contain toxic chemicals, and plans for safe disposal may need to be drawn up.

LOCAL EXPERIENCE: HENNOPS LAKE, CENTURION (See Appendix A)

Aim of strategy: To remove silt from Hennops Lake which is filling the dam and reducing its potential for watersports and recreation. Silt is caused by poorly managed construction activities and agricultural practices in the catchment.

Date strategy implemented: Ongoing. The dredger has been delivered but the pipeline, pump and silt dam must still be commissioned.

Capital costs: Approximately R560 000 (inc. VAT) for the dredger plus an additional R2,5m for civil work associated with the pumping of silt via pipeline to a slimes dam. This gives an overall capital investment of just over R3m.

Maintenance costs: Precise costs unknown at present, but estimated at R200 00/a.

Evaluation: Too early to assess.

H. ARTIFICIAL MIXING/AERATION

Cost: Medium to high	Timeframe: Short term

i) Principle

Artificial mixing of the water of the impoundment results in a greater mixed depth to photic zone ratio. This results in a reduction in the average time spent in the photic zone by the phytoplankton (algae).

ii) Typical problems addressed with this strategy

- Actively decreases the average time algae spend in the photic zone and photosynthetic production and growth are reduced, thereby reducing the algal standing crop.
- The net effect is to reduce the dependence of certain algal species on internal gas mechanisms which enable them to remain within the photic zone, and thus increase competition between the various species of algae.

Positive aspects	Negative aspects
• In Australia, algal dominance after mixing, shifted from the green algae to diatoms. • Chlorophyll *a* values can be reduced by up to 50%.	• In some cases internal loading of phosphate may increase after mixing by 300% as a result of re-solubilisation. • Transparency of water may also decrease. • More effective in deeper water bodies.

iii) General comments

- There are more conflicting arguments on artificial mixing than on any other lake restoration technique.
- Motor boats can also influence the circulation of phosphate within the impoundment.
- The use of this technique requires caution and is site-specific. In some instances it appears to have worked well, whilst in others it has created additional problems.

LOCAL EXPERIENCE: JAN SMUTS DAM, BRAKPAN (See Appendix A)

Aim of strategy: To create an environment acceptable for development around the dam by mixing and aerating the dam water. By disturbing the water and introducing oxygen to it, it is intended to change the predominant algal species from blue-green to green, thereby reducing the risk of scum formation which is unsightly and causes noxious odours on decay.

Date strategy implemented: September, 1992. During the first year, however, there were frequent aerator breakdowns and teething problems, but since August 1993, the aerators have operated continuously for 24 hours a day except during periods of standard maintenance.

Capital costs: R850 000 (1992) for the purchase and installation of 10 7,5KW Aire-O_2 aerators; R100 000 on cages and wooden platforms to protect and vandal-proof aerators; R50 000 to be spent shortly on steel mesh platforms to replace the stolen wooden platforms. The platforms over the aerators are accessible from the shore, therefore they can be used by anglers.

Maintenance costs: The Sewer Department is responsible for inspecting and cleaning the aerators. This takes approximately 1,5 man-hours/d. At R100/h labour costs, this amounts to R3 300/month (x22) or R39 600/a. General maintenance costs are estimated at R7 500/a. Power consumption costs total 7,5KW/a x 0,12c per unit of power consumed x 10 (aerators) x 24/h/d = R216/d, or R6 480/month (x30) or R77 760/a. Total operating costs thus amount to R124 860/a; say R125 000/a (1995).

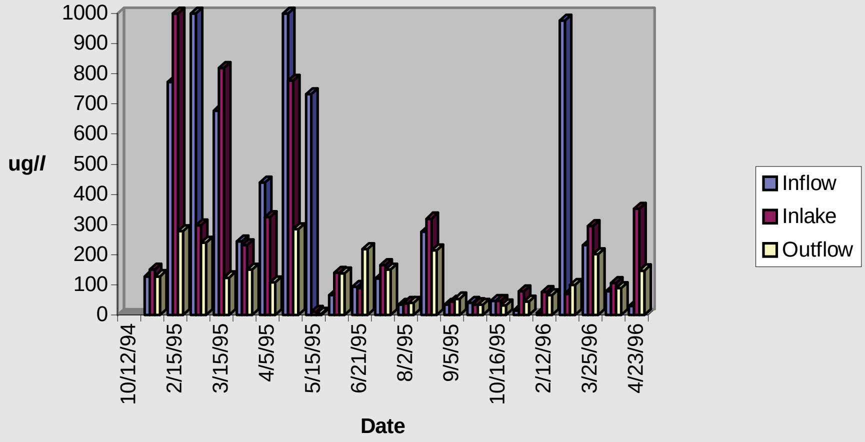
Evaluation:

The chlorophyll *a* results for Jan Smuts Dam indicate that potentially nuisance conditions for algae do remain within the lake, but the Brakpan Health Inspector has not received any complaints from the public since the installation of the aerators.

The other problem addressed by the installation of aerators is that of blue-green algae. A beneficial shift to green algae was expected. This occurred for a short period for which data was available. However, the data indicated that conditions for blue-green microcystis sp. (*Cyanophyta*) still remain. There is no data on the algal species composition prior to the installation of the aerators.

Continued overleaf

Chlorophyll *a* concentration in Jan Smuts Dam, Brakpan



Lessons learnt

It was not possible to accurately evaluate any change in algal species or numbers since no pre-management strategy data was collected. The collection of baseline data is essential to evaluate the success of a management strategy.

I. CHEMICAL DOSING OF PHOSPHORUS AND ALGAE USING ALUMINIUM SULPHATE AND COPPER SULPHATE

i) Principle

Cost: Medium **Timeframe:** Short term

The principle of using aluminium sulphate involves the formation of an aluminium hydroxide flocculant as a layer over the sediment, thus reducing the internal loading of phosphorus. Copper sulphate is used as an algicide.

ii) Typical problems addressed with this strategy

- Reduces internal loading of phosphate and high standing crops of algae and macrophytes.

Positive aspects	Negatives aspects
• Phosphate concentrations can be reduced by up to 60%. • Similar reductions in algal biomass have been recorded.	• In shallow impoundments, the persistence and beneficial effects of the chemical barrier may be short term. • As the water transparency increases, macrophyte and algal infestations may re-emerge.

iii) General comments

- Typical concentrations of 5.5mg/ℓ aluminium sulphate have been used.
- This strategy is best implemented as part of a suite of management options and not as a single measure.

J. CONTROL OF SUBMERGED AQUATIC PLANTS WITH CHINESE GRASS CARP

i) Principle

Cost: Low **Timeframe:** Long term

Chinese grass carp, *Ctenopharyngodon idella*, are introduced to impoundments with macrophyte (e.g. *Potomageton pectinatus*) infestations, which feed on the plants to reduce the standing crop, and thereby reduce the negative impacts associated with these plants.

ii) Typical problems addressed with this strategy

Infestations of macrophytes cause the following problems:

- The dense mats of the plant cause problems with boats and other users of the impoundments;
- The plant becomes tangled in motorboat engines;
- The plant causes problems for anglers, by entangling fishing lines.

Positive aspects	Negatives aspects
• Grass carp have been successfully used in South Africa in Germiston and Florida lakes. • Grass carp can survive cold water temperatures. • Generally fish survival rates are high. • Triploid (infertile) variety is as effective as normal (fertile) variety.	• Uncertainty in in-lake nutrient dynamics after introduction of fish. • The reduction in weed biomass may affect bird patterns (it is used as nesting material) and small fish patterns (it is used for shelter). • Bacteria and viruses may be introduced. • The availability of fish for stocking is restricted in South Africa.

iii) General Comments

- The relationship between the size of an impoundment, the extent of a macrophyte problem and the number of fish to introduce is not widely understood.

K. ALGAL CONTROL USING DECOMPOSING BARLEY STRAW

Cost:
Low
Timeframe:
Short term

i) Principle

The presence of decomposing barley straw in water has been shown in trials, both in the field and the laboratory, to contain the growth of a range of algal species in certain site-specific cases.

ii) Typical problems addressed with this strategy

- Problems associated with the development of large blooms of potentially toxic blue-green algae can be mitigated under certain conditions with the use of decomposing barley straw.

Positive aspects	Negative aspects
• In the laboratory 2.7g/m^3 inhibited growth of algae by 95%. • In field trials, 24 bales/ha (each bale = 20 kg) have shown satisfactory results. • Relatively low cost. • Environmentally friendly biological control.	• Actual factor inhibiting growth is unknown. • Works well only on smaller impoundments. • Unknown synergistic or cumulative effects on water quality. • May be effective only at certain sites suggesting other factors may also be important.

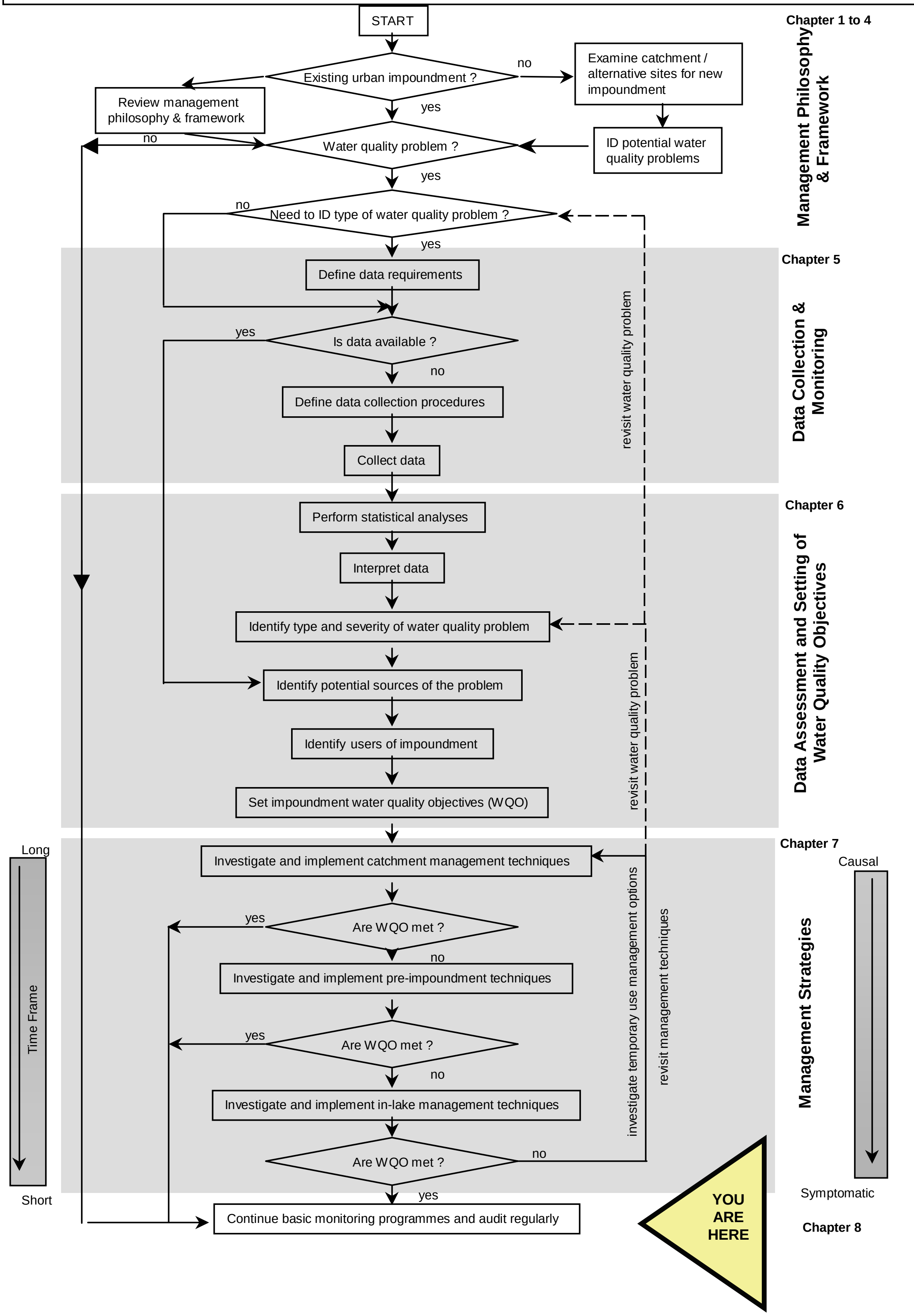
General comments

- The effect of barley straw appears to be that of inhibiting cell division, rather than killing of algae. It is therefore not an algicide.
- Once the barley straw is removed, algal growth rates return to normal.
- Although wheat and linseed straw also appear to work, barley straw remains the most effective.

7.7 Use management

Use management techniques are generally employed when the quality of water has deteriorated to a level where further treatment is required to render the water suitable for the desired purpose (usually domestic, agricultural or industrial use). In terms of recreation, use management largely involves passive responses such as advising against use of the water for certain recreational activities. Contact recreational watersports in such poor quality water are then undertaken at the individual's own risk.

FLOWCHART FOR USE OF THE MANUAL



CHAPTER 8: BASIC MONITORING PROGRAMMES

8.1 Introduction

Once a management strategy has been introduced for an urban impoundment, it is important to monitor the impact and success of the strategy. It is not uncommon for this step to be forgotten, particularly if success is quickly achieved in removing or reducing the visual impact of a water quality problem. Although such a level of success may stop public complaints, it is no guarantee that the water quality problem has been fully addressed and that it will not re-occur.

8.2 Purpose of basic monitoring

Basic monitoring programmes, therefore, should be put in place once a management strategy has been implemented, as a check for the following:

- to monitor the water quality in an impoundment, its catchment and downstream of the impoundment as a means of assessing the success of specific management techniques;
- to trace and monitor any changes in waste sources upstream of the impoundment; and
- to monitor changes in the use of the impoundment.

It is necessary to recognise that urban impoundments are part of a dynamic system and, as such, may be subject to fluctuations in water quality over time. By instituting a basic monitoring programme, changes in the water quality status of the impoundment can be swiftly recognised and investigated.

As is mentioned in Chapter 5, a water quality monitoring programme for an impoundment should be integrated with and supplement other monitoring programmes within the catchment. The basic monitoring programme does not necessarily have to include all the monitoring sites and water quality variables that were examined in identifying the water quality problems in an impoundment. Sampling frequency can also be reduced. However, it is recommended that sufficient monitoring stations and key water quality and quantity variables be retained to assess the success or otherwise of a particular management strategy, as well as to track the overall water quality in the impoundment. A minimum monthly sampling frequency is recommended and sufficient time should elapse before a definitive assessment is made on the success of the management strategy.

A list of organisations follows that could be approached regarding the siting of water quality monitoring stations, as well as for assistance in deciding which water quality variables to monitor, the sampling frequency, the location of testing laboratories, and procedures to follow in collecting and testing water samples.

Organisation	**Location**	**Contact number**
DWAF regional offices, local authorities, waste water treatment works, mines, universities	Countrywide	Consult local telephone directory
Institute for Water Quality Studies (DWAF)	Pretoria	012-808-0374
SABS	Pretoria	012-428-7911
Rand Water	Johannesburg	011-682-0911
Umgeni Water	Pietermaritzburg	033-341-1111
CSIR	Pretoria	012-841-4575

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CHAPTER 10: GLOSSARY OF TERMS

aesthetics: the beauty, attractive and scenic values of an object or place. The manner in which these values are deduced is subjective. In the case of urban impoundments, they are frequently described in terms of odour, colour and the presence of litter.

algae: a collective term referring to a wide range of pigmented, oxygen producing photosynthetic organisms usually present in surface waters. Virtually all aquatic vegetation without true roots, stems and leaves are regarded as algae. They are common inhabitants of surface water exposed to sunlight and also often form the basis for aquatic food webs. Excess algae or undesirable algal types can, however, become a nuisance and interfere with the uses of a water body. This can be a natural phenomenon, but is often the result of accelerated eutrophication (increasing nutrient concentrations) caused by wastes from human activities.

anthropogenic: human or man-made.

assimilative capacity: the capacity of a water body to accommodate, through processes such as dilution and chemical and biological degradation, a quantity of a substance without causing any known impairment of use.

bacteriological contamination: the contamination of water by pathogenic faecal organisms and microbes from which infectious and gastroenteric diseases may be contracted through ingestion. Human health can also be placed at risk, however, by viruses, algal toxins and other chemical wastes in water.

chemical oxygen demand (COD): the amount of oxygen required to oxidise all the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant.

chlorophyll: the green pigment in plants and algae that, during photosynthesis, captures sunlight energy and converts it into chemical energy in the form of carbohydrates. Chlorophyll *a* is a form of chlorophyll required in the biochemical reactions of photosynthesis. Chlorophyll is used as a measure of the quantitiy of algae in water.

clarity: refers to the depth to which light can penetrate a water body and is measured by the depth at which a Secchi disk (a 20 cm diameter disk with black and white quadrants) is visible.

eutrophic: refers to water, particularly in impoundments, which is high in nutrients and hence has the potential for excessive plant and algal growth (eutrophication).

diffuse (or non-point) waste source: the discharge of wastes from continuous or non-point sources, e.g. runoff or infiltration from fields or the veld. The volume and water quality of the discharge are generally difficult to measure and quantify.

effluent standard: a legally enforceable value or limit of a water quality constituent/variable in an effluent being discharged into a water body. The General Effluent Standards is a set of effluent standards published in terms of the Water Act which are applicable throughout South Africa. An effluent must comply with the whole set unless an exemption relaxing one or more of the standards has been issued by DWAF. The Special Effluent Standard is a set of effluent standards published in terms of the Water Act, which are applicable in certain river catchments in South Africa.

fitness of water: a judgement of the suitability of the quality of water for one of the four recognised water uses as well as for protecting and maintaining the health of the natural aquatic environment.

impoundment: a term that usually refers to man-made dams, but which is used in this Manual to also include natural lakes, pans and vleis.

lake: a water body formed by natural physical processes which has an inflow and an outflow and retains water for a longer period than the river in which it is situated. In South Africa, most lakes are coastal.

limnology: the study of freshwater systems.

macrophyte: any macroscopic form of aquatic vegetation, encompassing certain species of alga, mosses, ferns and aquatic vascular (woody and rooted) plants.

natural aquatic environment: the habitats, biotic components and ecological processes contained within rivers, impoundments and wetlands (including the outer edges or riparian zone). Terrestrial biota, which depend on the aquatic ecosystem for survival, are included in this definition, but not humans.

pan: a shallow, typically circular or oval shaped water body with no natural outlet (endorrheic). They are generally a feature of the inland plateau region of southern Africa.

pathogenic: disease-causing.

photic zone: the part of the water column penetrated by sunlight.

point waste source: the discharge of wastes from known discrete or point sources, e.g. an effluent discharge from an industry. The volume and water quality of the discharge can normally be measured and quantified.

pollution: the result of wastes which destroy the purity of water by making it foul or filthy, and a potential threat to life.

recreational water use: the use of water bodies for recreational activities. Full contact recreation is one of the categories of recreational water use that involves full-body water contact such as swimming. Intermediate-contact recreation includes activities with a high degree of water contact such as canoeing, wading, boating and fishing. Non-contact recreation involves no direct contact with water such as when picknicking or walking.

site-specific: conditions that are unique or specific to a certain site or locality.

target water quality range: a range of water quality which DWAF has, as a matter of policy, decided to strive to maintain. It corresponds with a “no effect” range.

urban impoundment: term used in this Manual to refer to man-made dams and natural lakes, pans and vleis which have become surrounded by urban development.

vlei: a local term typically used in southern Africa to describe floodplain areas, wetlands, marshes and sponge areas.

waste: an unwanted liquid, gaseous or solid substance.

water quality: term used to describe the physical, chemical, biological and aesthetic properties of water which determine its fitness for use and the protection of the natural aquatic environment.

water quality constituent/variable: term used generically in this Manual for any properties of water and the substances suspended or dissolved in it.

water quality criteria: defined in the *South African Water Quality Guidelines* (DWAF, 1993 and 1996) as scientific and technical information provided for a particular water quality constituent/variable in the form of numerical or narrative descriptions of its effects on the fitness of water for use and the protection of the natural aquatic environment.

water quality guideline: a set of information provided for a specific water quality constituent/variable. It consists of the water quality criteria, including the target water quality range for that constituent, together with other supporting information. The *South African Water Quality Guidelines* (DWAF, 1993 and 1996) consist of guidelines for domestic, recreational, industrial and agricultural water uses, as well as for the protection of the health of the natural aquatic environment.

water quality objective: a concentration or level, not to be exceeded, set for a specific water quality constituent/variable in a defined water body or portion of a water body.

water use: four broad categories of water use are recognised in the *Water Act (No 54 of 1956)*, namely, domestic, industrial, agricultural and recreational. DWAF's mandate also requires it to protect the health and integrity of the natural aquatic environment. The water quality requirements of these water uses and those of the protection of aquatic ecosystem form the basis on which the fitness for use of water is judged.

wetland: area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt.

APPENDIX A

AN ANALYSIS OF WATER QUALITY DATA AND MANAGEMENT TECHNIQUES AT THREE SOUTH AFRICAN URBAN IMPOUNDMENTS

EXECUTIVE SUMMARY

Three South African urban impoundments (viz. Jan Smuts Dam, Brakpan; Hennops Lake, Centurion; and Zoo Lake, Johannesburg), which experience typical water quality problems, were analysed in depth over a three-year study period.

The characteristics of each impoundment are described together with background information on the water quality problems experienced. The management strategies introduced at each impoundment to address the water quality problems are detailed, as well as an analysis of recent water quality data in order to assess the success achieved to date by each management technique.

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1. INTRODUCTION

1.1 Background

This appendix presents the results of an analysis of water quality problems and management techniques at three case study impoundments (i.e. Jan Smuts Dam, Brakpan; Hennops Lake, Centurion; and Zoo Lake, Johannesburg) over a three year period (1994-1996). The case studies describe the water quality problems encountered at each impoundment and the management techniques that have been implemented to tackle these problems, and assess the success of the management strategies to date.

The intention of the case study analyses is to focus on the practical realities faced by impoundment managers and to apply the urban impoundment management philosophy advocated in the main Manual. The Appendix also provides additional detail and guidance to the reader who is unfamiliar with data collection and water quality analysis for urban impoundment studies.

The basic approach to urban impoundment management described in the main Manual is presented schematically once more in Figure 1.1 overleaf to facilitate the discussion. The key areas of the management process discussed in this appendix largely cover Chapters 5 to 8 of the Manual and are detailed below in Table 1.1.

Table 1.1: Key Areas of the Urban Impoundment Management Process

Basic Data	Impoundment Location and Catchment Characteristics Impoundment History Impoundment Use Water Quality Problem Description Existing Impoundment Management Strategies and Costs
Monitoring	Status and Objectives of the Monitoring Programme Modifications to the Existing Monitoring Programme
Evaluation	Water Quality Synopsis Success of Impoundment Management Strategies
Conclusions	Conclusions and Recommendations

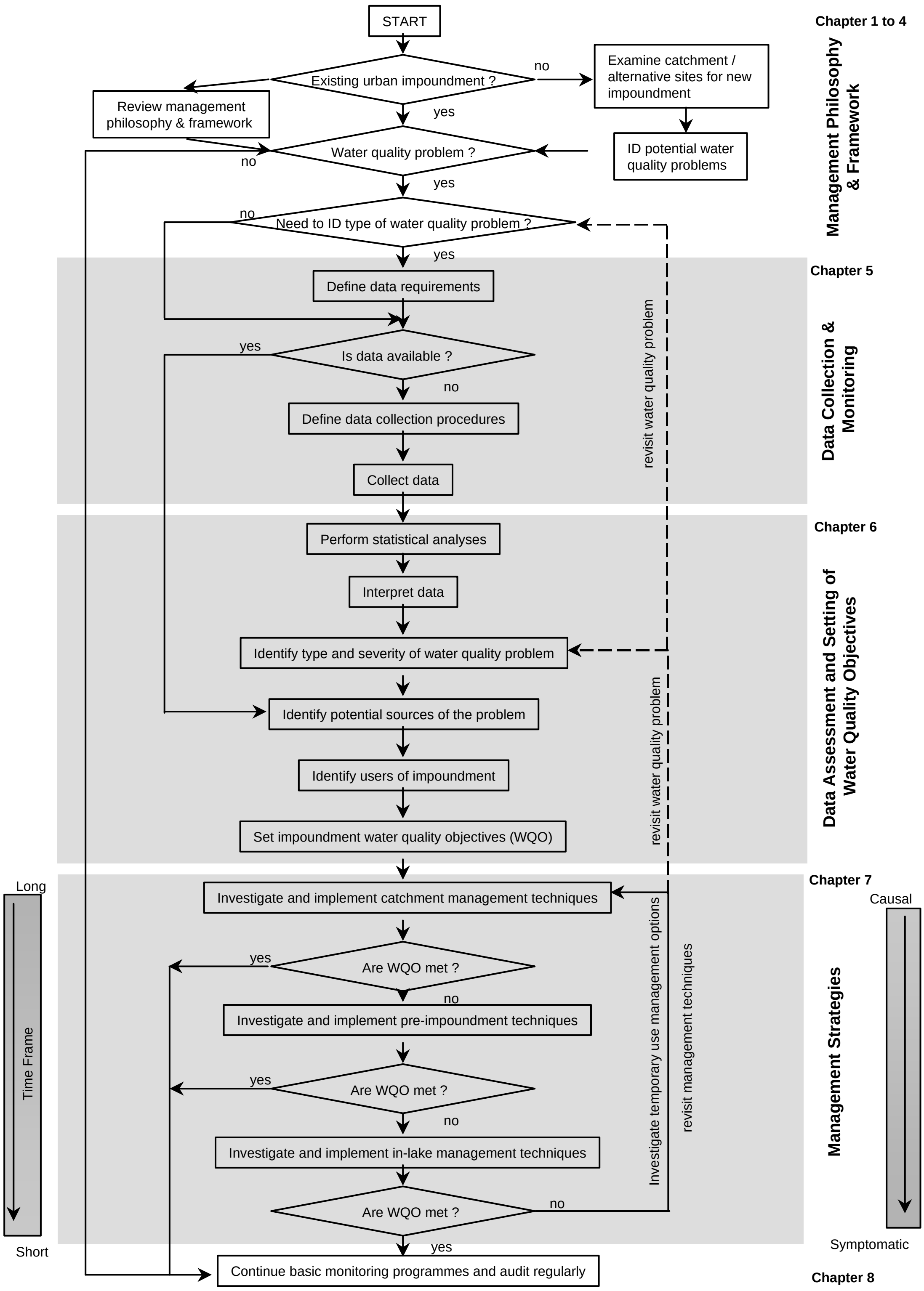


Figure 1.1: Flowchart for Use of the Urban Impoundment Manual

2. EVALUATION OF CASE STUDY IMPOUNDMENTS – JAN SMUTS DAM, BRAKPAN

2.1 Location and Catchment Characteristics

Jan Smuts Dam is a shallow, natural pan situated just north of the Brakpan CBD (Figure 2.1). It is at a height of 1 600 m above mean sea level (amsl), has a surface area of 70 ha and has a small island in the centre. Some of its basic characteristics are summarised in Table 2.1.

Table 2.1: Geographic and Physical Characteristics of Jan Smuts Dam

Geographic Location	26^o 13' S ; 28^o 22' E
Elevation	1 600 m amsl
Surface Area	70 ha
Volume	810 000 m^3
Mean Depth	1,2 m
Maximum Depth	1,4 m
Length	1 805 m
Width	875 m

The land use in the catchment is mixed. Approximately 50% of the catchment is occupied by residential areas, of which about two-thirds serve the medium to high socio-economic groups of the population and one-third the lower socio-economic segment. Commercial land and parkland each occupies approximately 20% of the catchment, whilst light and heavy industrial areas make up 5% each. A power station ash heap and refuse dump are situated on the northern shore of Jan Smuts Dam.

Stormwater runoff from certain areas of Brakpan drains into Jan Smuts Dam. The dam also receives treated effluent from a wastewater treatment works on its eastern shore. A stormwater drain flows into a small flooded quarry (approximately 100 m in diameter and over 30 m in depth), which is connected to the south-western part of the dam by a short canal. The dam, being a natural pan, has no outlet. During periods of high rainfall, water is pumped out of the dam into a tributary of the Blesbokspruit. During dry periods, there is no pumping from the dam.

2.2 Dam History

In the early part of this century, Jan Smuts Dam filled during the rainy season and dried out in winter. Since 1938, the Brakpan wastewater disposal works has discharged its treated effluent into the dam which now remains full throughout the year. Stormwater from central Brakpan also drains into the dam and maintains water levels.

In the past, water was abstracted from the dam for cooling purposes at a power station situated on the northern bank, but the power station is now closed. During the 1950s, the area around the southern shore was developed as a park and recreation resort. Jan Smuts Dam has experienced pollution problems since the 1940s and has an extensive history of investigation.

Figure 2.1: Location of Jan Smuts Dam

2.3 Dam Use

Although Jan Smuts Dam serves as a stormwater retention pond and as a receiving body for discharge from the Brakpan wastewater treatment works, its most visible use is as a recreation node for the people of Brakpan and neighbouring towns.

Active recreational uses include watersports such as sailing, motorboating and fishing. On the southern bank, an extensive recreational resort has been developed including a caravan park, children's playground, restaurant and picnicking facilities.

Water is abstracted from the dam to the Blesbokspruit catchment by 2 pumps in the reedbeds on the northern shore. These pumps operate throughout the summer and for about 30% of the time in winter. Water is also abstracted from the dam for dust suppression and irrigation by Hippo Quarries, by Modderfontein Consolidated Mine, the Brakpan Country Club and the Brakpan Municipality (which uses water from the quarry inlet to irrigate nearby sportsfields in winter).

2.4 Water Quality Problem Description

Jan Smuts Dam frequently experiences severe algal infestations resulting in the accumulation of dense scums of algae on the shores of the lake. These release noxious odours when they decay. The primary causes of the algal problems are the enrichment of the dam water with nutrients (mainly phosphorus and nitrogen) from the wastewater treatment works and from the stormwater runoff from the catchment. The algal scums usually form on the southern shore where they are blown by the prevailing winds from the north/north-west. These scums form a crust and reach a depth of 10-20 cm and a breadth of over 20 m.

2.5 Existing Impoundment Management Strategies and Costs (1995)

2.5.1 Installation of Floating Aerators

Aim of strategy: To create an environment acceptable for recreation and for development around the shores of the dam by mixing and aerating the dam water. By disturbing and introducing oxygen to the water, it is intended to change the predominant algal species in the dam from blue-green to green (the latter type usually being less problematic). This is an in-lake management strategy designed to address water use in the impoundment.

Date strategy implemented: September, 1992. During the first year, however, there were frequent breakdowns and teething problems with the aerators, but since August 1993, they have operated continuously for 24/hours a day except during periods of standard maintenance.

Capital costs: R850 000 for the purchase and installation of 10 7,5KW Aire-O_2 aerators; R100 000 on cages and wooden platforms to protect and vandal-proof the aerators; R50 000 spent on steel mesh platforms to replace the stolen wooden platforms. The platforms over the aerators are accessible from the shore so they can be used by anglers.

Maintenance costs: The Wastewater Department is responsible for inspecting and cleaning the aerators. This takes approximately 1,5 man-hours a day. At R100 per hour labour costs, this amounts to R3 300/month (x22) or R39 600/a. General maintenance costs are estimated at R7

500/a. Power consumption costs total 7,5 KW/h x 0,12c/unit of power consumed x 10 (aerators) x

24/hours/d = R216/d, or R6 480/month (x30) or R77 760/a. Total operating costs thus amount to R124 860/a; say R125 000/a.

Other relevant information: 10 aerators have been installed close to the southern shore to help disturb the water where the algal scums normally collect. The Aire-O_2 aerator is an aspirating propeller aerator/mixer, which consists of a motor, shaft, propeller and flotation device. The propeller, mounted near the end of a hollow drive shaft, turns rapidly to force the water outward past the end of the shaft. This movement of water creates a partial vacuum at the end of the shaft causing air above the waterline to be pulled through the hollow drive shaft and dispersed into the water. Flow patterns can be calculated by linking the zone of influence from one aerator to another. In Jan Smuts Dam, an anti-clockwise flow pattern along the southern shore has been created. Early problems experienced with the operation of the aerators in the dam were the result of using incorrect motors which also had to be watertight and vandal proof. It was originally recommended that 20 aerators be installed across the entire dam. Brakpan intends to install the remainder of the aerators in the future when it is expected that the northern shore of the dam will be developed for mixed land-uses (offices/small industry and residential).

2.5.2 Walling of Southern Shoreline

Aim of strategy: To allow easier access to the water for recreation whilst preventing algae being washed onto the shoreline, where it subsequently decays causing foul odours. The wall extends from the ash dump to the wastewater treatment works (which also has a walled front to the dam). This is an in-lake management strategy designed to address water use in the impoundment.

Date strategy implemented: September, 1992.

Capital costs: R350 000.

Maintenance costs: None to date.

Other relevant information: The wall is 300 mm high, although only about 150 mm is above the waterline. The wall was constructed behind a rock ballast layer on which was built a concrete slope to the foot of the wall.

2.5.3 Introduction of Fish

Aim of strategy: To introduce a new species of fish (kurper) for anglers at the dam which favours the consumption of algae. This is an in-lake management strategy designed to address water use in the impoundment.

Date strategy implemented: September, 1993.

Capital costs: R2 500.

Maintenance costs: None.

Other relevant information: 22 000 fingerlings of mainly Loskop Dam Blue Kurper together with some Dwarf and Vlei Kurper were introduced to Jan Smuts Dam by the fish farm/aquarium at Hartebeespoort Dam. Carp and barbel constitute the bulk of the other fish found in the dam and these two species are those most often caught by anglers.

2.5.4 Litter Traps

Aim of strategy: To prevent litter entering the dam through the stormwater pipes. This is a pre-impoundment management strategy designed to address the transport of waste into the impoundment.

Date strategy implemented: January, 1995.

Capital costs: R15 000.

Maintenance costs: None to date. The litter traps are emptied by the Parks Department as part of normal maintenance and litter control in Jan Smuts Park.

Other relevant information: The old quarry at the inlet to the dam receives the main stormwater channel to Jan Smuts Dam and also acts as a litter trap, except during high flows when litter is washed into the main lake. The cages around the aerators prevent litter from clogging their motors. Litter that accumulates around the cages is removed by the Wastewater Department when inspecting and cleaning the aerators. The Brakpan landfill on End Street has recently closed (March 1995) and has now received a closure permit from the Department of Water Affairs and Forestry (DWAF). The sealing of the landfill by the construction of an evaporation dam to catch leachate from the dump was completed in July 1995. Any leachate reaching the dam through the stormwater system should thus now have ceased. The ash dump from the old power station on the northern shore is currently being reclaimed for brick-making. Reclamation will probably be complete in 3 years time. Dust from the dump is blown into the dam during high winds. There has been an application to abstract water from the dam for use in dust suppression, but this has not yet commenced.

2.5.5 Recreational Policy

Aim of strategy: To restrict recreational activities to those considered safe, given the quality of water in the dam. This is a water use management strategy which is a passive response and designed to advise against use of the water for certain contact recreational activities.

Date strategy implemented: Precise date unknown, but sometime in the early 1980s.

Capital costs: None, but possible loss of recreational amenity and income to local economy.

Maintenance costs: None.

Other relevant information: The recreational policy forbids the use of long shaft boats on the dam because of its shallowness and the likelihood of these craft stirring up the bottom sediments. This could aggravate the poor water quality of the dam by releasing phosphates and other nutrients bound in the sediments. This decision was first implemented in the early 1980s and an application to use long shaft boats again on the dam in 1991 was rejected. It has been decided, however, to permit the use of hydroplane boats on the dam as these disturb the water column, but not the bottom sediments, thereby reducing conditions favourable to the development of algal scums. No water-skiing, windsurfing or canoeing has been permitted on the dam since 1987 because of fears about the toxicity of the algae-infested water and its safety for contact recreation. The safety in particular of people with a weak heart, children and dogs was of concern. Tests carried out by the CSIR in 1992 showed that algal samples taken from fish in the dam were not toxic, although water samples were microbiologically unsafe. The policy regarding which recreational activities to permit on the dam is a

precautionary safety measure to prevent potential health problems, but obviously detracts from the overall recreational attractiveness of the dam.

2.5.6 Chemical Dosing

Although chemical dosing has occurred at Jan Smuts Dam, no planned strategy has actually been followed. However, relevant information in this regard is provided below since the chemical dosing which has occurred will have affected the water quality situation.

Copper sulphate dosing of the dam was used by Brakpan in the past as a strategy to combat algal growths. This was more than 15 years ago, however, and no information on the success of this strategy is available. It is presumed that this is no longer practised because of the costs involved.

In 1986, ferric chloride dosing of the effluent from the wastewater treatment works on the eastern shore commenced. This was done to reduce the phosphate load in the effluent so as to comply with the <1mg/ℓ phosphate level specified in the Special Phosphate Standard. The dosing has the effect of removing phosphate, in the form of ferric phosphate, into the sludge which is then treated in the plants' digesters. In 1988, ferric chloride was replaced with ferric sulphate because there was a shortage of ferric chloride at the suppliers. In 1991, ferric chloride was again used. This meant a reduction in the phosphate load in the effluent, but an increase in the chloride/sulphate content. Dam water sometimes has a higher phosphate content than the effluent from the wastewater treatment works. This is probably the result of phosphate entering the dam via the stormwater system and through the resuspension of sediments.

No chlorination of the treated effluent takes place at the wastewater treatment works. This is because there is no difference between the height of the water in the dam and that of the effluent from the sand filters, which would mean that the dam water would be chlorinated rather than the effluent. There is also concern about the effect that chlorination would have on the fish life in the dam. Both Rand Water and DWAF monitor effluent quality at the wastewater treatment works.

2.6 Monitoring Programme – Key Changes

Historically, Brakpan has carried out an extensive monitoring programme at Jan Smuts Dam, largely because of its water quality problems and the impoundment's intensive use for recreational activities. Eight monitoring points have been routinely monitored in the dam until recently for a wide number of water quality variables. These monitoring points were mainly concentrated in the southern area of the dam where most recreational activities take place. As a result of financial constraints, this programme was curtailed shortly before the commencement of the case study, to three variables, i.e. pH, electrical conductivity and dissolved oxygen.

With the co-operation of the local authority, the wastewater treatment works laboratory and the study team, it was possible to extend the water quality monitoring programme again for the purposes of this study. Problems in the data collection exercise continued during the study period, however, because of a shortage of resources and manpower at the local authority.

In order to better understand the eutrophication problem, the existing monitoring programme at Jan Smuts Dam was modified as follows:

- two additional sampling stations were identified; and
- the following water quality variables were added: total dissolved solids, alkalinity, suspended solids, chlorides, sulphates, orthophosphate, total phosphate, nitrate and nitrite, ammonia, Kjeldahl nitrogen, chlorophyll *a* and algal identification.

The addition of the two sampling stations was intended to provide data on the in-lake water quality across the full extent of the dam. Since Jan Smuts Dam suffers from frequent high concentrations of algae, data for the additional water quality variables was needed to assess the success of the implemented management strategies.

2.7 Water Quality Synopsis

The prime water quality problems in Jan Smuts Dam are eutrophication-related. The manifestations are frequent high concentrations of algae resulting in the formation of scums which, on decay, produce noxious odours. To address this, three management strategies were implemented almost simultaneously. These were the installation of aerators, the walling of the southern shoreline of the dam (where algal scums collect as a result of the prevailing wind) and the stocking of the dam with algae-eating fish. In order to determine the success of these strategies, it is necessary to evaluate the algal status of the dam. In order to accomplish this, an assessment of the algal nutrient status is also required. This involves analysing the water quality sample results for phosphate (PO_4), ammonia (NH_4), nitrates (NO_3), chlorophyll *a* and algal identification. Summary statistics for nutrient concentrations (PO_4, NH_4, and NO3) are presented in Table 2.2 (p.11). The location of the sampling sites is shown schematically in Figure 2.2.

There are two primary inflows to Jan Smuts Dam:

stormwater runoff via a canal at site 1;
treated wastewater effluent at site 5.

2.7.1 Phosphorus Compounds

Phosphorus (P) plays a major role in the structure of nucleic acids (DNA) and in energy-storing molecules (ATP) in cells (Addiscott *et al*., 1991). A significant portion of the phosphorus within a water system may be unavailable for use by plants because it is adsorbed onto suspended solids or bound to elements such as iron, aluminium and calcium (Addiscott *et al*., 1991).

A significant source of phosphorus in river systems affected by man's activities is treated wastewater effluent.

The median orthophosphate (PO_4-P) concentration in the stormwater canal during the study period was 0.2 mg/ℓ as P. The effluent from the wastewater treatment works had a median concentration of 0.4 mg/ℓ as P. In-lake concentrations were in the region of 0.4 mg/ℓ as P during the same period. These results would indicate that the main source of phosphate in the dam is the wastewater treatment works effluent.

However, a full phosphate budget was not performed on the lake because of a lack of specific data on sediments and the role they play in phosphate recycling in Jan Smuts Dam. It could, therefore, also be possible that internal loading of phosphate from the sediments could be contributing to the overall phosphate balance.

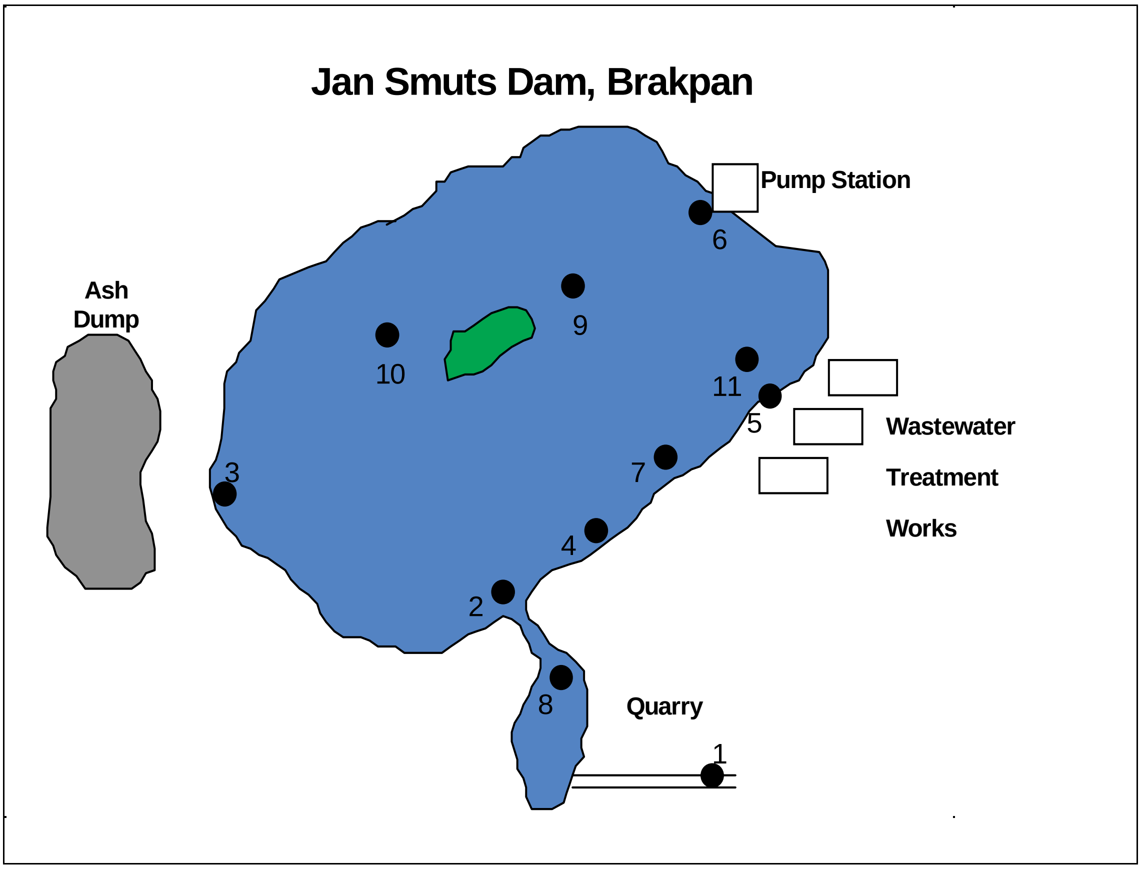


Figure 2.2: Location of Sampling Points in Jan Smuts Dam

2.7.2 Nitrogen Compounds

During the study period, water entering the lake by way of the stormwater canal had a median ammonia concentration of 1.0 mg/ℓ as N. Water from the wastewater treatment works had an average ammonia concentration of 1.8 mg/ℓ as N. The average ammonia concentration within the lake was 1.4 mg/ℓ as N.

For nitrate, the stormwater canal had an average concentration of 5.5 mg/ℓ as N and the wastewater effluent 3 mg/ℓ as N. In-lake, the concentration averaged approximately 3 mg/ℓ as N. Time series plots for nitrate for the two inflows (sites 1 & 5) and one in-lake site (site 9) are presented in Figure 2.3 (p.12).

The nitrogen cycle consists of a balance between inputs to and losses from the aquatic ecosystem. Sources of nitrogen would typically be rainfall and dry fallout from the atmosphere, nitrogen fixation within the water body and inputs from stormwater and wastewater effluent. Sinks or losses of nitrogen include outflows from lakes, reduction of nitrates to nitrogen as a gas and sedimentation of inorganic and organic nitrogen compounds to the bottom of the lake or dam (Wetzel, 1983).

Table 2.2: Nutrient Statistics for Sampling Stations in Jan Smuts Dam

Js1	mean	median	Min	Max	95 th percentile	count
PO_4	0.21	0.20	0.00	0.55	0.52	13.00
NH_4	0.95	1.00	0.20	1.60	1.54	13.00
NO_3	5.32	5.50	0.00	8.30	8.25	13.00
js2	mean	median	Min	Max	95 th percentile	count
PO_4	0.77	0.30	0.06	6.60	2.88	14.00
NH_4	2.49	1.60	0.50	7.20	6.06	13.00
NO_3	2.29	2.80	0.10	5.20	4.24	13.00
js3	mean	median	Min	Max	95 th percentile	count
PO_4	0.41	0.40	0.20	0.80	0.77	14.00
NH_4	1.53	1.35	0.20	3.80	3.41	14.00
NO_3	2.53	2.45	0.00	5.60	5.28	14.00
js4	mean	median	Min	Max	95 th percentile	count
PO_4	0.42	0.38	0.20	0.80	0.79	14.00
NH_4	1.58	1.40	0.70	3.50	2.85	14.00
NO_3	3.17	3.60	0.00	9.60	7.00	14.00
js5	mean	median	Min	Max	95 th percentile	count
PO_4	0.50	0.40	0.30	1.00	0.94	13.00
NH_4	1.68	1.80	0.60	3.00	2.88	13.00
NO_3	2.73	3.00	0.70	5.00	4.58	13.00
js6	mean	median	Min	Max	95 th percentile	count
PO_4	0.46	0.40	0.20	0.90	0.84	14.00
NH_4	1.82	1.39	0.50	5.90	4.02	14.00
NO_3	3.49	3.20	0.60	9.10	6.83	14.00
js7	mean	median	Min	Max	95 th percentile	count
PO_4	0.38	0.30	0.20	0.90	0.77	14.00
NH_4	1.75	1.40	0.20	5.20	3.64	14.00
NO_3	2.64	3.30	0.00	6.00	5.81	14.00
js8	mean	median	Min	Max	95 th percentile	count
PO_4	0.25	0.20	0.00	0.90	0.61	14.00
NH_4	1.34	1.35	0.40	2.70	2.25	14.00
NO_3	3.47	2.60	0.90	18.00	8.64	14.00
js9	mean	median	Min	Max	95 th percentile	count
PO_4	0.40	0.30	0.10	1.10	0.97	14.00
NH_4	1.68	1.45	0.70	5.30	3.81	14.00
NO_3	2.86	3.10	0.40	5.20	4.94	14.00
js10	mean	median	Min	Max	95 th percentile	count

PO_4	0.40	0.30	0.20	0.80	0.74	14.00
NH_4	1.69	1.40	0.20	5.60	3.98	14.00
NO_3	2.86	3.35	0.30	5.20	4.75	14.00
js11	mean	median	Min	Max	95 th percentile	count
PO_4	0.40	0.40	0.20	0.70	0.61	10.00
NH_4	1.50	1.02	0.70	3.50	3.05	10.00
NO_3	2.87	3.20	1.00	4.50	4.50	10.00

All figures are mg/ℓ as P and mg/ℓ as N as applicable.

PO_4 – Orthophosphate

NH_4 – AmmoniaNO_3 –

Nitrates

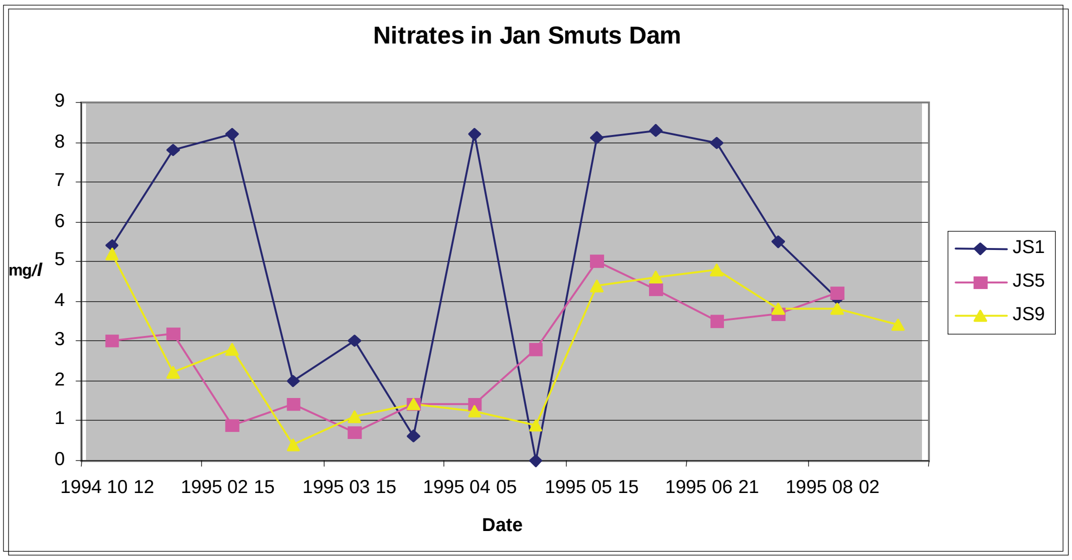


Figure 2.3: Nitrate Concentrations in Jan Smuts Dam

Nitrate is the usual form of inorganic nitrogen entering a dam from an urban area via stormwater runoff. Nitrate is assimilated into organic nitrogenous compounds within organisms (Wetzel,1983). This organic nitrogen is bound and cycled in the aquatic ecosystem, and during normal metabolism and death, is liberated as ammonia. Nitrates are one of the important nitrogen sources for plants and bacteria.

Generally, phosphate is the nutrient which controls the amount of growth of algae but should phosphate be in abundance, nitrogen can become the limiting nutrient. The first approach in managing nutrient levels within an impoundment is to reduce the amount of phosphate in the water. Should this not be practicable and phosphate is still in abundant supply, the management of nitrogen can also be investigated.

Time series plots for ammonia for the same stations as described in the nitrate section are presented in Figure 2.4.

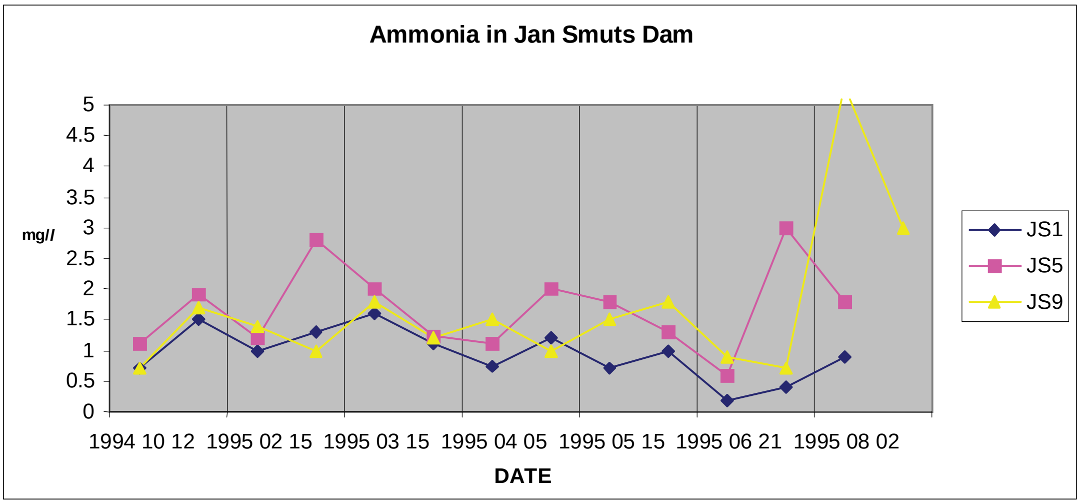


Figure 2.4: Ammonia Time Series for Jan Smuts Dam

Ammonia in water is present primarily as NH_4^+. However, a fraction of the ammonia is also present as disassociated NH_4OH or free ammonia (Wetzel, 1983). This fraction is pH and temperature dependent and is toxic to aquatic life. As the temperature and pH rise so the proportion of disassociated NH_4OH increases and the toxicity increases. DWAF suggests a water quality guideline value of 0.015 mg/ℓ as N for free ammonia (disassociated NH_4OH or NH_3). The corresponding concentration of total ammonia at pH 7 and an average daily temperature of 18°C (typical average summer conditions in South Africa) is 9 mg/ℓ as N. To illustrate the temperature and pH effects, at pH 8.5 and temperature 25°C, the corresponding concentration of total ammonia is 0.6 mg/ℓ as N.

As a nutrient source for algae and plants, ammonia is an energy-efficient source of nitrogen. Nitrates must first be reduced to ammonia before the nitrogen can be assimilated by plants. Among the blue-green algae, the highest growth rates occur when ammonia is the nitrogen source. This occurs at a number of differing light intensities and conditions (Wetzel,1983).

At Jan Smuts Dam, the total ammonia concentrations did not produce free ammonia concentrations, which would be toxic to aquatic life (i.e. >0.015 mg/ℓ as N). However, at the concentrations found in the dam, there is still sufficient nitrogen available to maintain a high blue-green algae standing crop.

2.7.3 Algal Populations

As identified above, there are sufficient nutrients in the water to maintain high algal populations, and this is confirmed in the chlorophyll *a* concentrations for the dam. Table 2.3 presents summary statistics for the sampling sites at Jan Smuts Dam.

Table 2.3: Chlorophyll *a* Concentrations in Jan Smuts Dam (as μg/ℓ)

Site No.	js1	js2	js3	js4	js5	js6	js7	js8	js9	js10	js11
Mean	4.78	466.9	364.8	296.9	237.1	130.2	292.1	119.8	156.5	131.5	141.4
Median	4	125	137	182	111	127	146	74.5	152.5	112	110
Min	0	7.2	17.68	38	9.45	5.244	12.012	6.829	8.11	10.305	0.488

Max	20	3607	3680	2212	937	285	1945	363	492	278	313
95 th percentile	10	1583.95	950	644.15	792.7	277.05	816.8	357.7	298.15	259.7	290
Count	21	22	21	22	22	22	22	22	22	22	21

Median chlorophyll *a* concentrations within the lake vary from 74.5 μg/ℓ to 182 μg/ℓ. DWAF has identified chlorophyll *a* concentrations of above 30 μg/ℓ as a visual nuisance for the recreational use of water bodies.

A time series plot for chlorophyll *a* at the three in-lake sites, 9, 10 and 11, is presented in Figure 2.5.

A number of trends are noticeable from Figure 2.5. Firstly, there was a general decrease in chlorophyll *a* concentrations throughout the dam over the late summer season and into the autumn of 1995. This could have been a result of a change in algal species towards those that are more adaptable to the cooler weather.

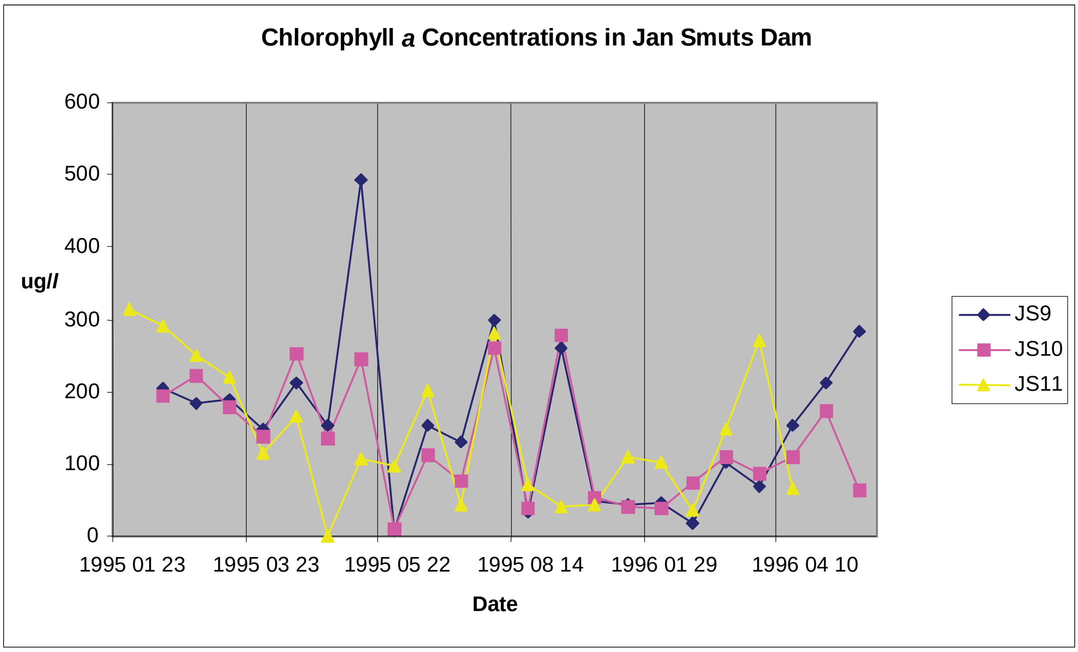


Figure 2.5: Chlorophyll *a* Concentrations in Jan Smuts Dam

During winter there was an increase in chlorophyll *a* concentrations. The orthophosphate, nitrate and ammonia data reflects no significant change in concentrations over winter and thus no significant increase in chlorophyll *a* concentrations would be expected. The change in chlorophyll *a* could therefore be as a result of a change in algal species.

The decrease in chlorophyll *a* concentrations during the first part of the wet summer season, is probably a result of mixing caused by increased flow into the lake. There may also be some loss from any spillage from the dam as the volume exceeds capacity.

The algal species data for Jan Smuts Dam is presented in Figure 2.6. It can be seen from this area distribution curve that at the end of winter the dominance of algal species shifts from *Cryptophyta* to *Chlorophyta*. The *Cryptophyta* group of algae produces dense stands during winter when the temperatures are lower and the light conditions are reduced (Wetzel, 1983).

Chlorophyta are green algae which are a large and morphologially diverse group of algae. As a consequence, they are nearly always present but can be expected to be dominant in conditions where they can compete effectively. Two significant interruptions to the sampling programme (as a result of manpower problems) occurred

at Jan Smuts Dam during the study period and data is only available for a limited period (four months). It was therefore not possible to conclude what the dominant algal species was during the summer period (when blue-green algae could be expected to dominate) nor to detect firm trends in algal species distribution.

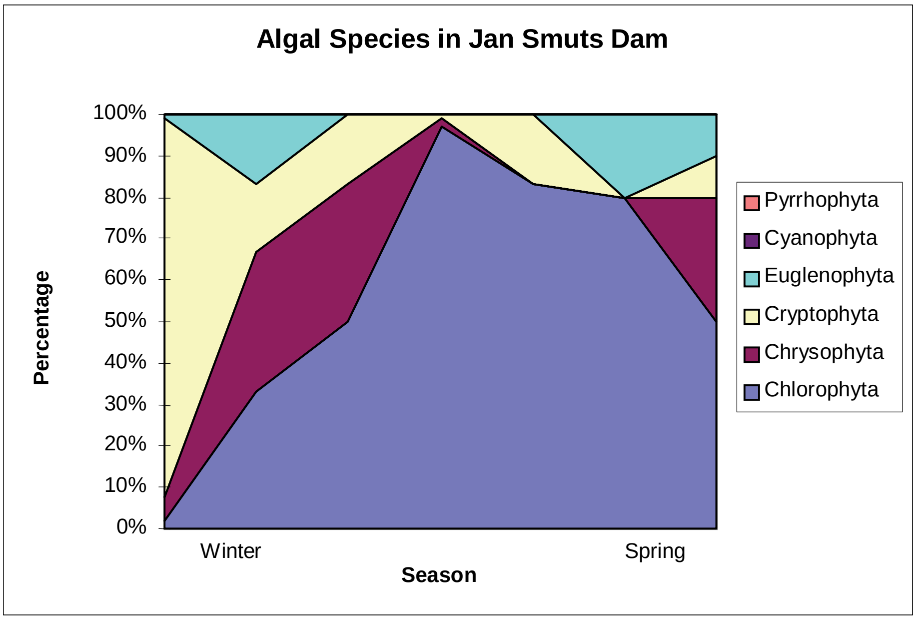


Figure 2.6: Algal Species Distribution in Jan Smuts Dam

In order to determine whether the Jan Smuts Dam is susceptible to changes in phosphate concentrations, the chlorophyll *a* data and the orthophosphate data were compared. Figure 2.7 presents the relationship between chlorophyll *a* and orthophosphate.

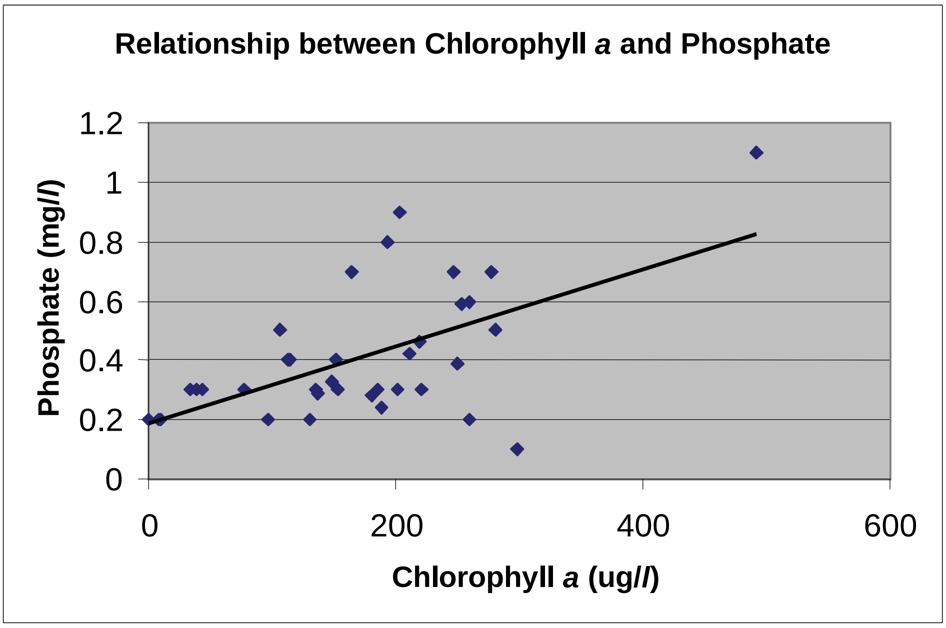


Figure 2.7: Relationship between Chlorophyll *a* and Phosphate for Jan Smuts Dam

The correlation coefficient indicates a weak relationship between chlorophyll *a* and phosphate concentrations (r^2=0.34). This would suggest that some other factor is also controlling the growth of algae in the dam. The relationship between the N:P ratio and chlorophyll *a* is presented in Figure 2.8. From this graph, it can be seen that as the ratio between nitrogen and phosphate decreases there is a general increase in chlorophyll *a*. This would tend to suggest that nitrogen concentrations in the dam are important in controlling the concentrations of algae. Nevertheless, the persistently high concentrations of chlorophyll *a* indicate that, in any case, there is sufficient nutrient availability in Jan Smuts Dam to maintain a healthy algal standing crop.

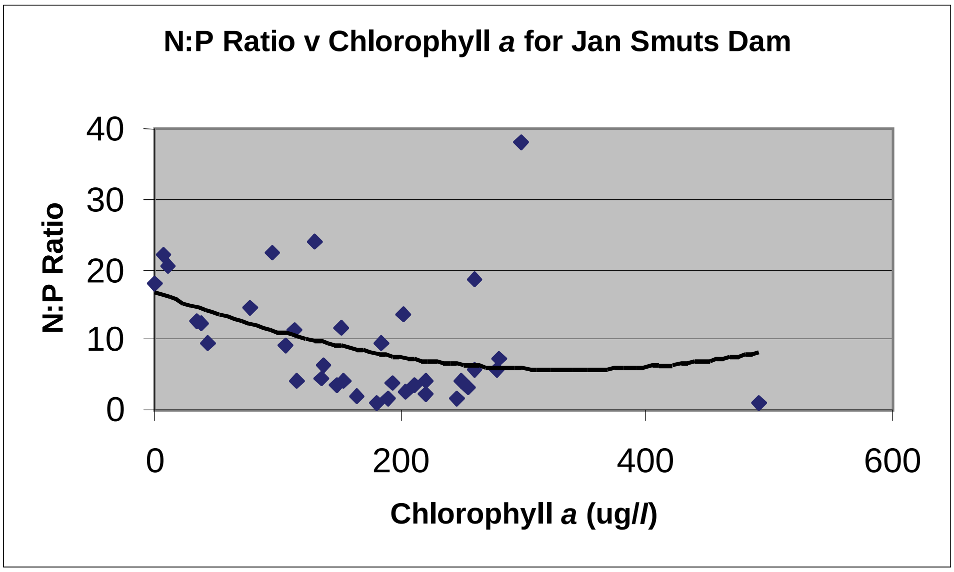


Figure 2.8. Relationship between N:P ratio and Chlorophyll *a*

It should be noted that certain green algae, such as *Scenedesmus* sp., are able to thrive at phosphate concentrations above 0.02 mg/ℓ as P, and reach their maximum population density when the concentration is just 0.5 mg/ℓ as P. The blue-green alga *Oscillatoria rubescens* does not reach its maximum population density until the phosphate concentration is at 3 mg/ℓ as P. The phosphate results from Jan Smuts Dam indicate that in general phosphate concentrations did not reach levels as high as 3 mg/ℓ as P. This may be due in part to unfavourable climatic conditions during the study period (i.e. the lack of long hot spells with little wind) for the formation of blue-green algae. Despite this, there was sufficient orthophosphate in the lake to sustain nuisance algal concentrations in excess of 30 |g/ℓ.

2.8 Success of Management Strategies

The main aim of the three management strategies implemented at Jan Smuts Dam was to control the amount of algae present in the dam and the subsequent deleterious effects on its use. The three strategies were implemented almost simultaneously. This makes an assessment of each individual strategy virtually impossible since there may be synergistic or cumulative effects arising from the combination of strategies.

The chlorophyll *a* results for Jan Smuts Dam indicate that potentially nuisance conditions for algae are prevalent all year round. Prior to the implementation of the management strategies, blue-green algal scums resulted in frequent complaints to the Brakpan Health Inspector from impoundment users. Since implementation, no complaints have been recorded. During high wind events, visual observations made by the study team indicate that water still manages to wash over the southern shoreline wall, but that no major odour problems were detected on the banks from decaying algal scums.

The wall has succeeded in preventing large-scale washing of algae and other debris onto the southern shoreline, although algal sums appear to have declined in any case following simultaneous installation of aerators in the dam. The wall is not very effective in high winds when water is easily washed over the wall onto the embankment.

As a result of the aeration management strategy, a beneficial shift from blue-green algae to green algae was expected. The algal identification data indicated that for a four-month period, the dominant algal species was *Cryptophyta* and C*hlorophyta* (green algae). No data on summer algal concentrations was available and thus the presence or absence of blue-green algae, e.g. *Microcystis* sp. (*Cyanophyta*), still remains unknown. There is no data on the algal species composition immediately prior to the implementation of the strategies. Historically however, blue-green algae have been a problem in Jan Smuts Dam.

Brakpan is happy with the success achieved with the aerators to date. The aesthetic problems (visual/odour) previously associated with thick algal scums have disappeared, apart from those resulting from occasional accumulations of algae in the reedbeds on the northern shore.

Approximately 22 000 fingerlings of mainly Loskop Dam Blue Kurper, together with some Dwarf and Vlei Kurper, were introduced to Jan Smuts Dam. The main aim of this strategy was to introduce fish to eat algae. Generally fish such as kurper favour green algae as blue-green algae are unpalatable. There is no scientific evidence as to the success of this strategy although from sight and catches made by anglers, the kurper appear to have bred successfully. The gravel covering much of the bed of the dam is apparently suited to the breeding requirements of the kurper. There was a belief that the kurper would not survive the cold conditions in winter in the shallow waters of the lake, but this appears to have been no problem. It is believed that there may have been a recovery in the number of carp in the dam as a result of barbel now being able to feed on both the kurper as well as young carp.

The water quality data indicates that there is a sufficient standing crop of green algae for the fish populations to thrive but there is little evidence that these fish populations are having a significant effect on the population of algae. Thus, although algae have been observed in the stomachs of gutted kurper caught in the dam, the success of the strategy could not be unequivocally determined. Although success has been achieved in macrophyte control in South Africa, the control of algae by fish is still by and large experimental.

All the stormwater pipe inlets to Jan Smuts Dam from the Brakpan CBD are above the waterline. The litter traps installed at the pipe inlets have therefore been reasonably effective in preventing litter and debris from entering the dam and this has improved the general aesthetics at the impoundment. During high flows and after the first rains, however, the lids of the traps tend to pop off. The traps would thus probably be more effective if they were larger.

The prime motivation for the implementation of the management strategies at Jan Smuts Dam was the number of complaints received from the dam users about the decay of algal scums on the shores of the impoundment. Since implementation, no such complaints have been received and therefore it can be concluded that the strategies have been partially successful.

It must be borne in mind, however, that the management techniques introduced at Jan Smuts Dam are in-lake strategies, which would appear to have achieved only limited success in treating the symptoms of eutrophication. The high nutrient and chlorophyll *a* concentrations still remaining in the water confirm that the causes of eutrophication still require attention. Alternative management strategies to do this would include removing or sealing the nutrient rich sediments in the dam; improving the quality of the wastewater effluent; and diverting poor quality stormwater (e.g. first summer rains) or flushing the impoundment.

3. EVALUATION OF CASE STUDY IMPOUNDMENTS - HENNOPS LAKE, CENTURION

3.1 Location and Catchment Characteristics

Hennops Lake is located within the main commercial node of Centurion. It has served as the focal point around which shops, offices and recreational facilities have been developed over the past decade. The lake covers 7,1 ha and has a volume of 145 000 m^3. Basic characteristics of the lake are shown in Table 3.1.

Table 3.1: Characteristics of Hennops Lake

Geographic Location	25° 51' S; 28° 11' E
Elevation	1 410 m AMSL
Surface Area	7 ha
Volume	145 000 m^3
Mean Depth	1,7 m
Maximum Depth	2,5 m
Length	600 m
Width	120 m

The catchment of Hennops Lake extends over a wide area (Figure 3.1). To the east and south-east, the catchment is drained by the Riet River, which has its origins in the Kempton Park area and is impounded by Rietvlei Dam, a bulk water supply source for the city of Pretoria. The outflow from this dam is known as the Sesmylspruit, which is more commonly referred to as the Hennops River, before it flows into Hennops Lake. However, because of the demands for water supply from Rietvlei Dam, Hennops Lake receives very little runoff from this part of the catchment. Instead, the bulk of the water feeding the lake originates from the Kaalspruit and Olifantspruit, which drain the area immediately south of the lake in the vicinity of Midrand and Tembisa. The Kaalspruit joins the Olifantspruit near Olifantsfontein where a wastewater treatment plant is located. The Olifantspruit and Sesmylspruit join to form the Hennops River near Irene, before flowing into Hennops Lake. The land use in the main catchment feeding the lake (the Kaalspruit and Olifantspruit) is mixed, but is made up of parkland or veld (40%), low density residential areas serving the medium to high socio-economic groups (30 %), high density areas serving the low socio-economic group (25%) and commercial land (5%). Downstream of Hennops Lake, the Hennops River flows into the Crocodile River, which in turn drains into the Hartbeespoort Dam.

3.2 Dam History

Hennops Lake is a man-made impoundment, which was constructed comparatively recently in 1983, and around which Centurion's central business district has subsequently been developed.

Figure 3.1: Hennops Lake Catchment

3.3 Dam Use

Hennops Lake is a classic example of the construction of a man-made impoundment in order to enhance and add value to surrounding commercial developments, as well as serving as a focus for recreational activities.

The lakeside offices and shopping centre enjoy a pleasant atmosphere within which to conduct business activity whilst extensive recreational facilities have been provided to attract visitors. These include the musical fountain in the lake itself, the Atlantis Water Park just upstream of the lake and the Hennops River Hiking Trail which runs between the Centurion Park Cricket Stadium (half a kilometre upstream of the lake) and the Zwartkop Nature Reserve, about 12 km downstream of the lake. Open spaces have been developed along the banks of the Hennops River downstream of the lake, including a golf course, whilst wetlands unsuitable for building purposes form a habitat for many bird species.

Recreational activities associated with the lake itself include boating, canoeing, windsurfing, angling and occasional swimming.

3.4 Water Quality Problem Description

In-lake problems at Hennops Lake are predominantly bacterial contamination and sedimentation. The sources of these problems, however, are in the upper reaches of the catchment, as far afield as Tembisa and Olifantsfontein. Bacterial contamination results from blocked sewer systems upstream in Tembisa and the exceeding of the capacity of the Olifantsfontein wastewater treatment works. The sources of the sediment are poor agricultural practices in the catchment, and construction activities and denudation within Midrand, Tembisa and other township areas.

3.5 Existing Impoundment Management Strategies and Costs (1995)

3.5.1 Chlorination of Inflow

Aim of strategy: To chlorinate the inflow water to Hennops Lake during winter thereby reducing the bacteriological contamination of Hennops Lake to a level which would not be detrimental to watersport activities. This is a pre-impoundment strategy designed to address the transport of contaminants.

Date strategy implemented: May, 1993.

Capital costs: R32 300 for the purchase and installation of a chlorination system. The system includes a 1 ton chlorine drum, a 10 000 g/h chlorinator, a diffuser and associated pipework.

Maintenance costs: Approximately 10 chlorine cylinders are used each year which, at a cost of R4 200 per cylinder, amounts to R42 000/a. A further R5 000/a is incurred in maintenance costs. This excludes the costs of water usage in the system, therefore annual maintenance costs can be said to total about R50 000/a.

3.5.2 Copper Sulphate Dosing

Aim of strategy: To treat and destroy algal blooms which accumulate in the lake, particularly around the inlets to the musical fountain. This is an in-lake strategy and addresses the water use of the impoundment.

Date strategy implemented: Exact date unknown, but copper sulphate dosing was done within the lake in the mid-1980s to treat excessive algal blooms. Dosing continues around the musical fountain on an ongoing basis.

Capital costs: None.

Maintenance costs: Copper sulphate crystals from 25 kg sacks are emptied in to the coffer dam around the musical fountain twice a month. The cost of each 25 kg sack is R76,25. The maintenance cost is therefore R152,50 per month.

3.5.3 Construction Of Weir To Divert Sewer Overflows

Aim of strategy: To divert the polluted baseflow in the Kaalspruit north of Tembisa back into the main outfall sewer and on to the Olifantsfontein wastewater treatment works. This is a catchment strategy and aims at addressing the effective delivery of wastewater treatment.

Date strategy implemented: January, 1994.

Capital costs: R18 750.

Maintenance costs: None to date.

Other relevant information: The diversion weir was introduced as an emergency measure to reduce bacteriological contamination of the watercourse. This had resulted from inadequate maintenance of sewers in the Tembisa area and the growth of informal settlements in the catchment without on-site sanitation (Ivory Park). The weir draws off 50-70 ℓ/s from the base flow (approximately 60-90% of the flow in winter).

3.5.4 Upgrade of Olifantsfontein Wastewater Treatment Works

Aim of strategy: To expand the treatment capability of the wastewater works from 38 Mℓ/d to 108 Mℓ/d whilst improving the quality of effluent discharged to the Olifantspruit. This is a catchment strategy and is aimed at improving the quality of treated wastewater released to the river system.

Date strategy implemented: April, 1995.

Capital costs: R90m.

Maintenance costs: Unknown.

Other relevant information: The treatment works purifies the wastewater emanating from Tembisa, Rabie Ridge, Clayville and Olifantsfontein. Although Ivory Park is not connected to a sewer network, a large proportion of the aqua-privies in the area discharge into manholes on the main outfall sewers to the Olifantsfontein wastewater treatment works. The effluent is a major contributor to the permanent flow in the Hennops River and the final effluent has to comply with the Special Phosphate Standard. Provision has been made to chlorinate the final effluent from Olifantsfontein and should the new extensions to the plant be commissioned successfully, an improvement in the quality of the final effluent discharged to the river can be expected.

3.5.5 Dredging of Hennops Lake

Aim of strategy: To remove silt from Hennops Lake, which is filling the dam, and reducing its potential for watersports and recreation. This is an in-lake strategy and addresses the water use of the impoundment.

Date strategy implemented: Ongoing. The dredger has been ordered and delivered. The pipeline, pump and silt storage dam must still be constructed.

Capital costs: Approximately R560 000 for the dredger plus an additional R2,5m for civil work associated with the pumping of silt via pipeline to a slimes dam. This gives an overall capital investment of just over R3m.

Maintenance costs: Precise costs unknown at present, but estimated at R200 000/a.

Other relevant information: This strategy has still to be implemented. The delivery of the dredger has taken place (December, 1995), whilst the construction of the pipeline and slimes dam will only commence later. The original intention was to release the silt dredged from the lake into the Hennops River downstream of the dam wall. This option was rejected, however, because of the environmental impact this would have on the species diversity and biomass in the river. A volume of 75 000 m^3 of silt needs to be removed from the lake. The depth of the silt varies from 1,8 m at the inlet to the lake to 0,8 m at the outlet. It will take the dredger at least two years to dredge the lake. The silt will be dredged from the lake and pumped to a slimes dam, which will now most probably be established near the Highveld Techno-Park development south of the N1 freeway. At the slimes dam, the silt will be dried and the clean water pumped back to the river.

3.6 Monitoring Programme – Key Changes

The Centurion local authority has an extensive monitoring programme covering catchment sites as well as in-lake sites. The economic impact of poor quality water in Hennops Lake has ensured that important data is collected frequently. The original monitoring programme focused on the key water quality issues, namely bacteriological and nutrient problems. In order to identify specific changes to the water quality within the lake, however, it was necessary to modify the existing programme as follows:

- The existing sampling network in the catchment and in the lake is fairly comprehensive. Nevertheless, three additional in-lake locations were identified to permit a comprehensive evaluation, two locations on the pedestrian bridge and one additional point at the inflow.
- The following water quality variables for analysis were also added: total dissolved solids, alkalinity, chlorides, sulphates, chlorophyll *a* and algal identification.

3.7 Water Quality Synopsis

The prime water quality problem in Hennops Lake is bacteriological contamination resulting in its reduced potential use for recreation. Three of the five management strategies are aimed at addressing this water quality problem. These are the routing of base flow in Tembisa to the wastewater treatment works, the upgrading of the Olifantsfontein treatment works and the chlorination of the inflow to Hennops Lake. Two secondary problems are the silting up of the lake and the periodic growth of nuisance algae for which dredging and chemical dosing respectively are the management strategies. In order to determine the success of all the management strategies, it is necessary to assess the catchment and in-lake microbiological conditions as well as suspended sediment and algal populations.

3.7.1 Bacteriological Populations

Summarised statistics for bacteriological populations within Hennops Lake and its catchment area are presented in Table 3.2. The location of the sampling sites is presented in Figure 3.2.

Table 3.2: Summarised Statistics for Bacteriological Populations in Hennops Lake (counts/100 mℓ)

Site		Median	Mean	Min	Max	95 th	Count
Hennops Bridge Middle	F. coliforms	0	563	0	10 000	2 200	41
	Total coliforms	250	2697	0	29 000	14 125	40
Hennops Inflow	F. coliforms	1 000	2 527	0	16 500	12 600	53
	Total coliforms	2 500	17 870	0	510 000	30 000	51
Hennops Outflow	F. coliforms	500	2 898	0	36 000	10 000	53
	Total coliforms	2 250	7 836	0	56 000	20 675	52
Tembisa	F. coliforms	50 750	66 990	950	550 000	166 750	52
	Total coliforms	87 500	240 447	2000	3 300 000	700 000	51
Kaalspruit	F. coliforms	9 500	20 469	100	400 000	57 000	51
	Total coliforms	21 000	90 866	1000	2 200 000	248 250	50

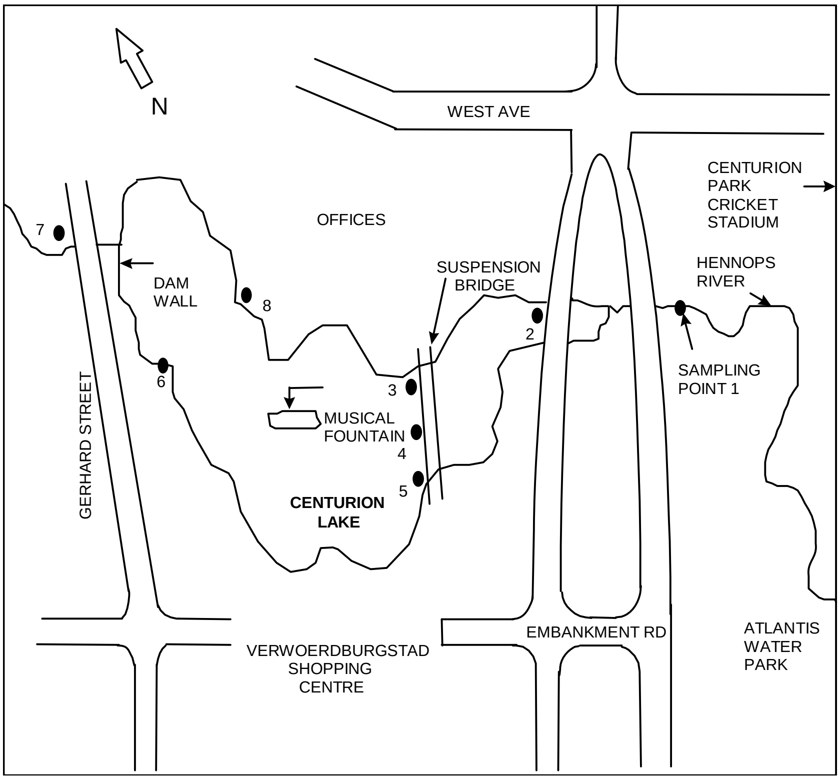


Figure 3.2: Water Quality Monitoring Sites at Hennops Lake

It is evident from Table 3.2 that the prime source of bacteriological contamination is in the upper reaches of the catchment, downstream of Tembisa (also see Figure 3.3). During the study period (November 1994 to January 1996) the basic sewer infrastructure in Tembisa could not cope with the demands placed on it by a growing population. This led to blockages of the sewer systems resulting in turn in contamination of the stormwater systems with wastewater.

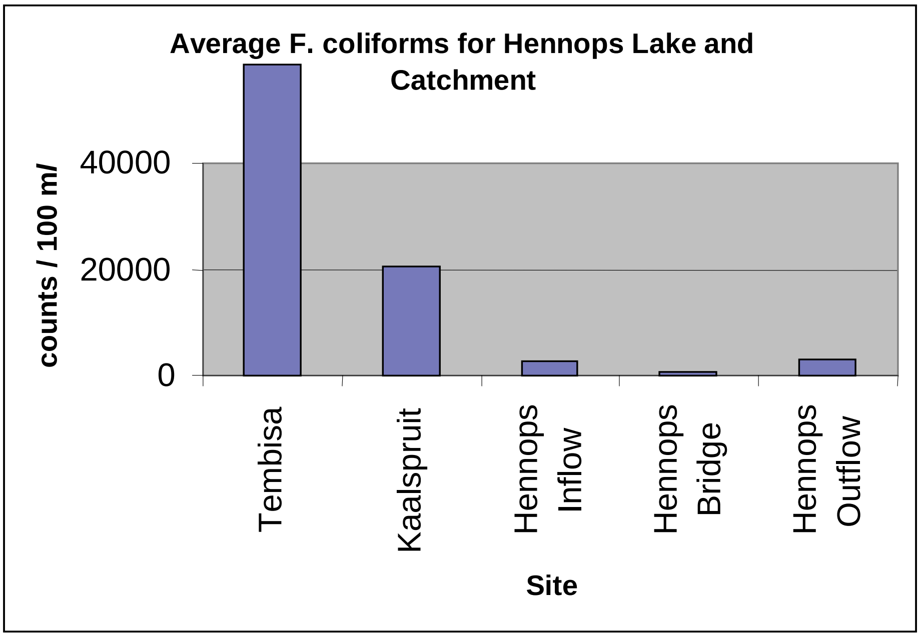


Figure 3.3: Faecal Coliforms in the Hennops Lake and Catchment Area

Bacterial contamination can originate from a number of sources:

- wastewater treatment works effluent;
- direct contamination from humans and animals;
- blocked sewers and drains; and
- naturally occurring populations exploding as a result of man's activities.

The prime influence of increasing numbers of bacteria in water is on human health. Use of the water for drinking, recreation and fishing can be negatively affected if the bacterial populations increase above a safe level.

Water abstracted for treatment to potable standards will generally remove bacterial contamination. However, certain species of bacteria, such as *Cryptosporidium*, are difficult to remove and as such may still cause health problems.

Water, which is used directly, however, such as for agricultural purposes and recreation, is generally not treated, and therefore a potential does exist for health problems to occur.

Bacteria which are implicated in health-related issues include:

- faecal coliforms;
- coliphages; and
- protozoan parasites.

Inhalation of pathogens during water-skiing can cause respiratory problems. Surface contact may cause eye, skin, ear and wound irritations. Many bacterial organisms occur naturally in the aquatic environment, but exposure may still be a hazard. Polluted water conditions (such as increased nutrients and suspended material) can also exacerbate increases in bacterial numbers, leading to an increase in the health hazard (DWAF, 1993). Studies in the US have shown that the levels of *E. coli* (an indicator organism for faecal contamination) in water show a high correlation with swimming related gastric illnesses (DWAF, 1993).

Coliphages are bacterial viruses which have been suggested as indicators of the presence and fate of human viruses in water. Coliphages require a coliform bacteria for replication, and therefore the presence of coliphages would indicate the presence of coliform bacteria (DWAF, 1993).

Relatively little is known about protozoan parasites in recreational water (DWAF, 1993), since they have been primarily identified in connection with domestic water use. An example of a protozoan parasite is *Cryptosporidium*. Infection occurs by ingestion of cysts or oocysts and disease takes the form of gastro-enteritis, diarrhoea, vomiting and subsequent weight loss (DWAF, 1993).

For practical purposes, chlorination of the inflow to Hennops Lake occurs during winter only. Thus any changes as a result of this management strategy will only be seen during this time. Figure 3.4 presents faecal coliform data for the Kaalspruit, upstream of Hennops Lake and for the inflow to Hennops Lake itself.

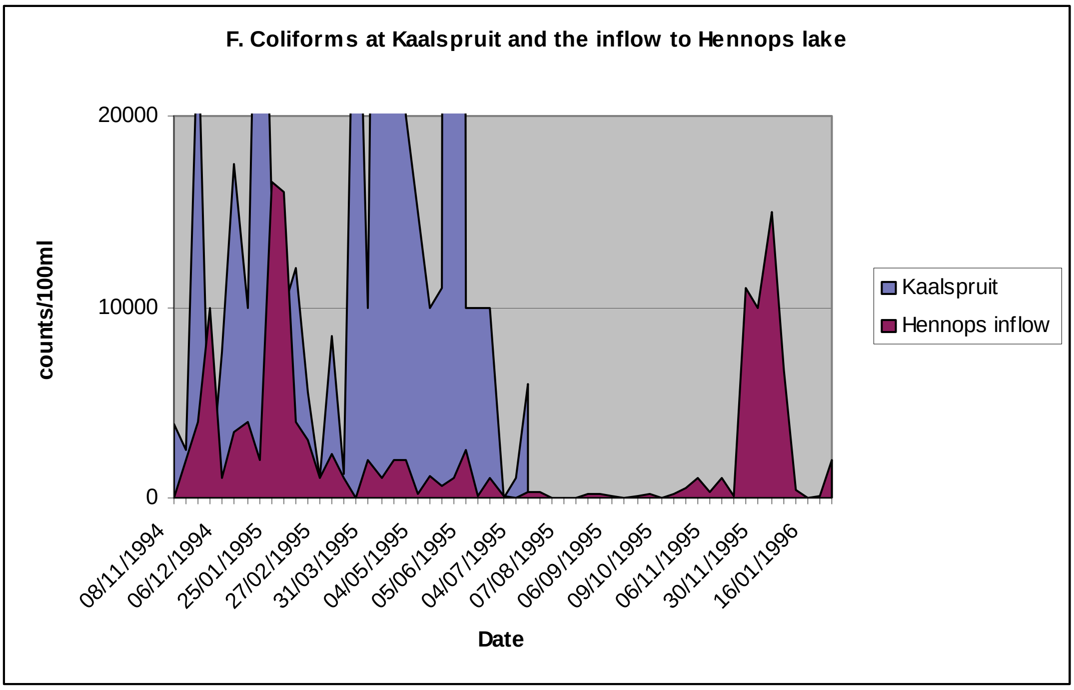


Figure 3.4: Faecal Coliform Results for Kaalspruit and Inflow to Hennops Lake

The results indicate that significant concentrations of bacteria are present in the Kaalspruit, but that concentrations are significantly lower at the lake inflow. The sampling site at the inflow to the Hennops Lake is at the point where the chlorination takes place, and thus localised disinfection is clearly occurring, although a certain amount of bacterial die-off in the river can be expected between the Kaalspruit and Hennops Lake.

Figure 3.5 shows that during summer, high concentrations of bacteria are still found at the inflow to the lake. In winter these values have decreased by an order of magnitude.

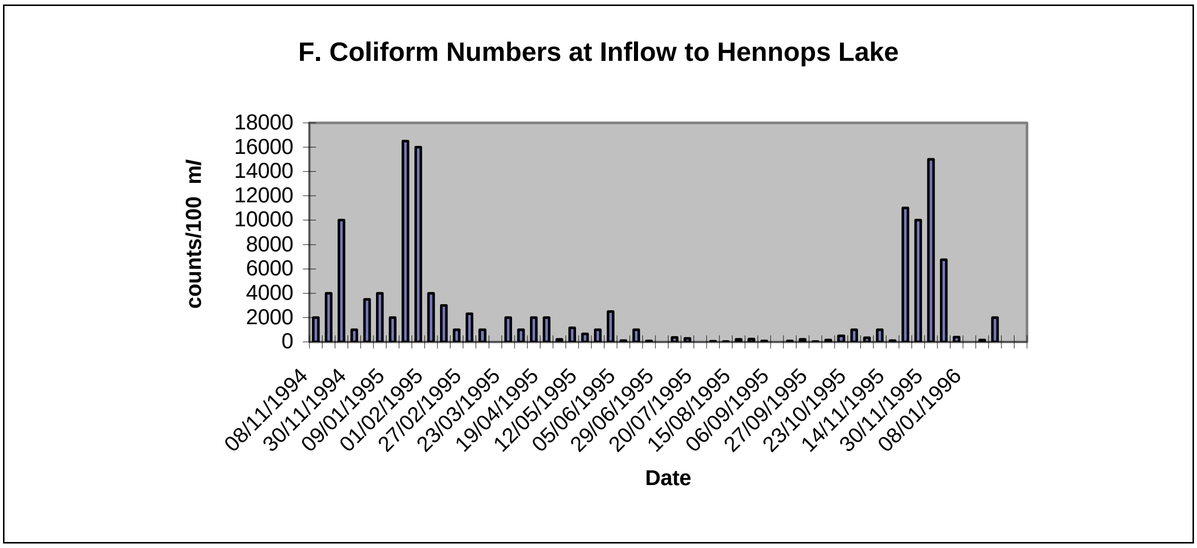


Figure 3.5: Faecal Coliform Numbers at Inflow to Hennops Lake

The presence of bacteria across the lake is presented in Figure 3.6. It can be seen from the time series graph, that during summer high concentrations of bacteria are present throughout the lake, but that during winter, these are reduced.

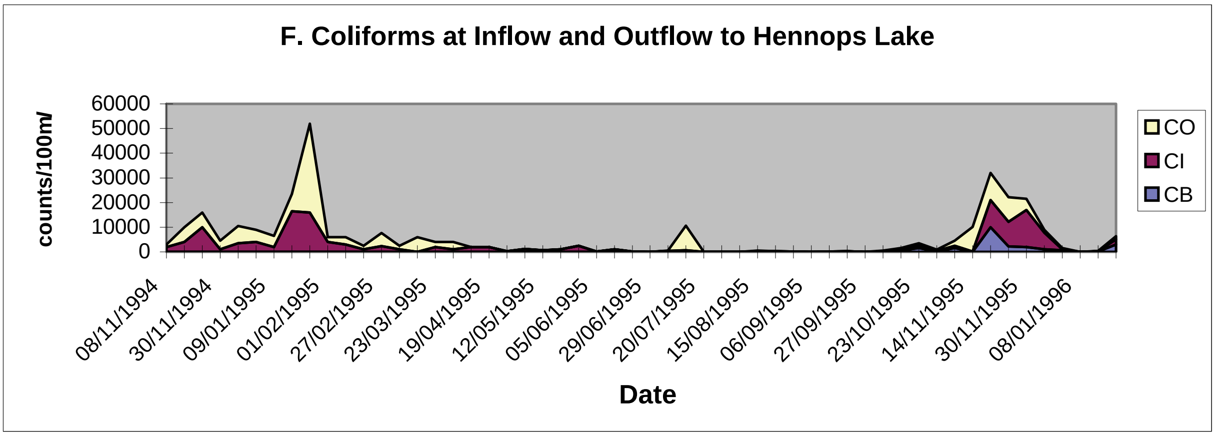


Figure 3.6: Faecal Coliform Results for the Inflow to Hennops Lake (CI), the Bridge over the Lake (CM) and for the Outflow to Hennops Lake (CO)

3.7.2 Phosphate Loading of Hennops Lake

To achieve a reduction in phosphate loading to Hennops Lake, the Olifantsfontein wastewater treatment works was upgraded in 1995 and a diversion weir was constructed near Tembisa to divert poor quality runoff to the wastewater treatment works. An analysis of the phosphate data for the Kaalspruit, upstream of the lake (Figure 3.7), indicates that there has been a reduction in phosphate concentrations from Tembisa to the Kaalspruit. This indicates that some success has been achieved in reducing phosphate loads as a result of the diversion weir, although dilution and a small amount of biological uptake will also occur. There is, however, still a high concentration of phosphate in the water entering the lake, suggesting that it may still be too early to identify whether the wastewater treatment works upgrade has resulted in any improvement in water quality in the Kaaslpruit downstream of the works.

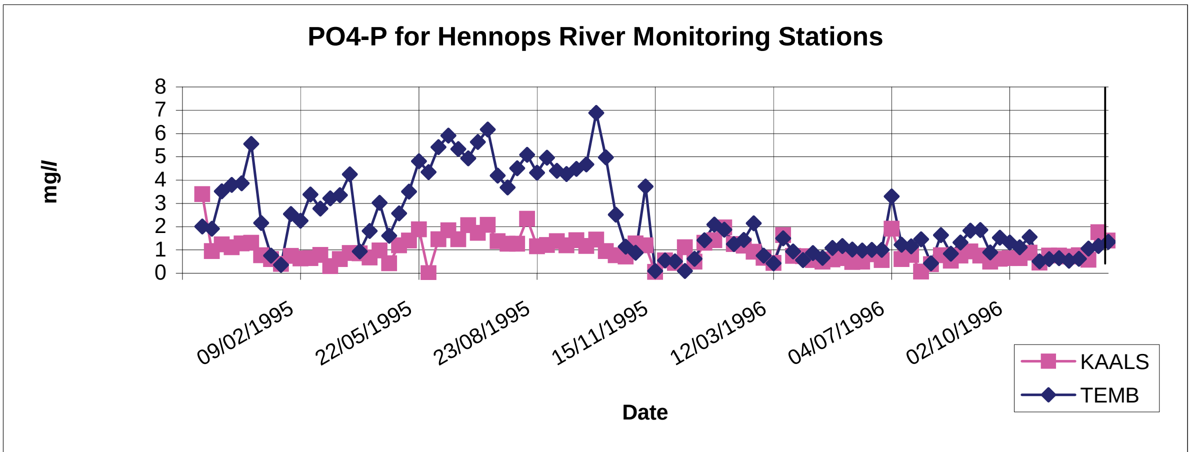


Figure 3.7: Phosphate Concentrations in the Catchment of Hennops Lake at Stations Kaalspruit (Kaals) and Tembisa (Temb)

These high levels of phosphate are reflected in Hennops Lake (Figure 3.8).

Concentrations in Hennops Lake have a different pattern to those found in the Kaalspruit, but one interesting point is the gradual accumulation of phosphate in the lake until it flushes in summer. The high concentrations of suspended sediment in the impoundment and thus the limitation to algal production (as seen in the relatively low chlorophyll *a* values in winter) would tend to suggest that there is little uptake in the lake itself.

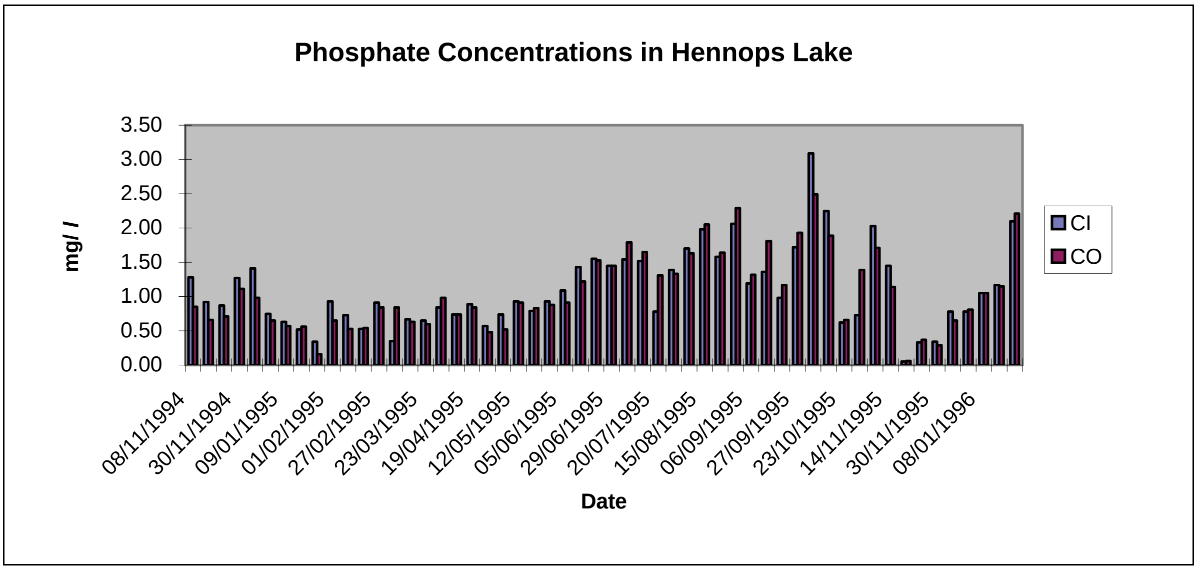


Figure 3.8: Phosphate Concentrations in the Inflow to Hennops Lake (CI) and the Outflow (CO)

3.7.3 Algal Populations within Hennops Lake

Although Hennops Lake is classified as a turbid impoundment, algal problems do manifest themselves, particularly at the musical fountain. Although the problematic algae present here are filamentous, chlorophyll *a* analysis indicates that at times relatively high concentrations of algae are still found. Unfortunately there are no sampling localities immediately adjacent to the musical fountain, and so an assessment of the success of the copper sulphate dosing strategy cannot be made. Chlorophyll *a* analysis for the site at the pedestrian bridge is presented in Figure 3.9.

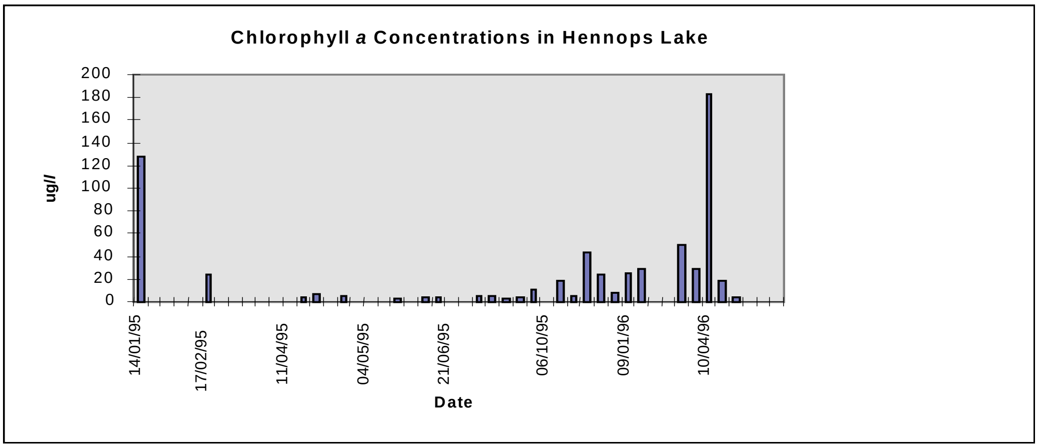


Figure 3.9: Chlorophyll *a* Concentrations in Hennops Lake

Figure 3.10 presents data on the algal composition within Hennops Lake.

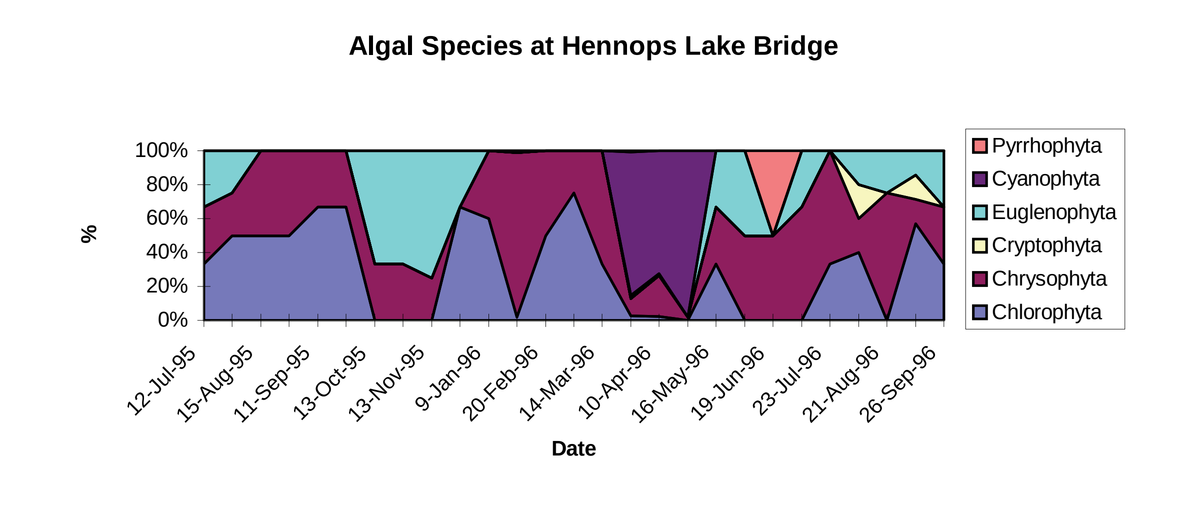


Figure 3.10: Algal Composition in Hennops Lake

The dominant algal species are *Chlorophyta* and *Chrysophyta*. The *Chlorophyta* are green algae which are common in lakes and dams throughout South Africa. The *Chrysophyta* include the diatom group. These species of algae are also referred to as the yellow algae. Unlike other types of algae, diatoms are able to absorb silica from the water (Schelske, 1975). Diatoms are common in South African lakes and dams and generally thrive in cooler winter conditions when light availability is reduced (as would be the case in turbid Hennops Lake).

3.7.4 Suspended Sediment

Sediments in rivers and dams are derived from a number of sources, such as:

- erosion (both natural weathering and man-induced as a result of denudation);
- poor agricultural practices;
- construction ; and
- urban activities.

Within the context of an urban impoundment, it can be expected that the site-specific nature of the catchment will dictate the volume of sediment originating from each of these sources.

The results of an increase in suspended sediment are:

- a reduction in depth of water as the layers of sediment build up and the suspended sediment drops out;
- the smothering of submerged plants, thereby affecting the productivity of the lake;
- a reduction in flood attenuation leading to increased inundation during high rainfall events; and
- the trapping of nutrients and organisms in the sediment which subsequently acts as a sink, from which resolubilisation and resuspension can occur, given the appropriate conditions.

Summarised statistical suspended solids concentration data for various sites in the Hennops Lake and catchment area are presented in Table 3.3.

Table 3.3: Suspended Solids Statistical Data for Hennops River and Catchment (mg/ℓ)

Site	Median	Mean	Min	Max	95 th	Count
Tembisa	32	40.49	8	346	82.4	53
Kaalspruit	36	62.23	4	620	176.4	52
Hennops Inflow	28	58.23	4	1150	81.6	53
Hennops Bridge Middle	24	51.98	4	983	68	41
Hennops Outflow	40	63.15	4	879	102.4	53

DWAF's Water Quality Guideline for the Aquatic Environment (1996) proposes a value of less than 100 mg/ℓ for total suspended solids to prevent harm to aquatic life. This means that the Hennops Lake and its catchment area fall within this guideline, but with average concentrations of 50 – 60 mg/ℓ in the inflow, the lake has silted up over time. This has resulted in up to 1 500 t/a of silt entering the lake. The data also shows that a similar amount of suspended solids leaves the lake as enters it. This does not suggest that no sedimentation occurs within the lake but rather that because of the accumulation of sediment over time, there is resuspension within the lake. The average depth of the lake has decreased to between 1 and 2 m, thereby allowing wind generated resuspension to occur.

Hennops Lake is rapidly silting up and the depth of accumulated sediment is significant. As a result of this, the decision has been made to dredge the lake. The dredger has been purchased and delivered, but actual dredging has not commenced, pending the results of a detailed environmental impact assessment (EIA) for the location of the slimes dam. There is a high sediment load entering the lake, as is seen in Figure 3.11. This results in settling of the sediment during periods of low wind, and relatively low flow. Again, there is a distinct seasonal trend, with greater concentrations being recorded in the summer, during periods of increased rainfall.

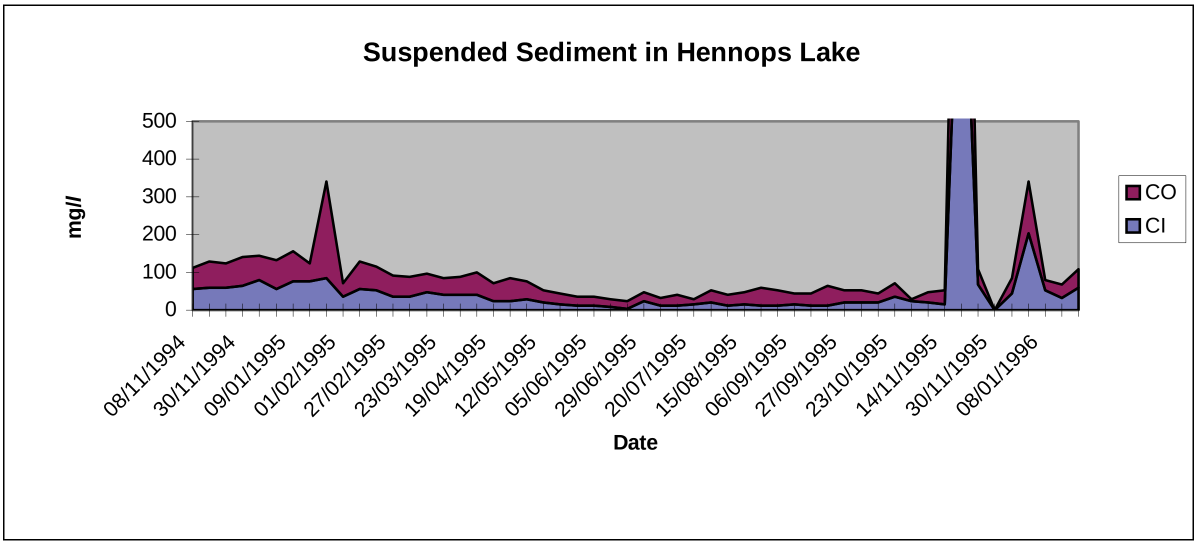


Figure 3.11: Suspended Sediment Concentrations in Hennops Lake for the Inflow (CI) and the Outflow (CO)

The data indicates that as the lake silts up, so there is a greater tendency to resuspend sediment, and this can be seen in Figure 3.11, where the level of suspended sediment is greater at the outflow than at the inflow, except during extreme inflow events.

The implications of the resuspension are that bacterial and nutrient levels in the lake can be significantly increased from inflow levels.

3.8 Success of Management Strategies

Chlorination of the water flowing into the lake has helped reduce *E.coli* counts in the lake during winter to below 2 000/100 mℓ on average (see Table 3.4), but chlorine dosing has not generally taken place during the summer periods because inflows and bacteria levels are too high in the wet season for chlorination to have any lasting effect - the chlorine is quickly carried through the lake and into the river system downstream. Furthermore, there is no flow meter at the point of inflow to assess the amount of chlorine required for dosing. Chlorination does not appear to have had any detrimental effect on fish life.

Table 3.4: Historical *E.coli* Data for Hennops Lake with and without Chlorination

PERIOD	AVERAGE *E.coli* COUNT
4/8/94 - 31/10/94 (Dosing on)	1 450/100 mℓ
4/11/94 - 7/3/95 (Dosing off)	7 600/100 mℓ
7/3/95 - 31/8/95 (Dosing on)	400/100 mℓ

This strategy has achieved its goal and during the period of study was deemed to be successful, permitting recreational activities to take place safely during the winter season.

Although there has been a decrease in phosphate concentrations from Tembisa to the Kaalspruit, there remains a significant residual phosphate load entering Hennops Lake. The strategies to divert the poor quality runoff from Tembisa and the upgrading of the Olifantsfontein wastewater treatment works will have contributed to some extent towards reducing the pollution load downstream in the Hennops River, but an insufficiently long data record is presently available to assess or quantify this accurately.

No evidence regarding the success of the copper sulphate dosing strategy has been obtained, but copper sulphate apparently acts quickly (within a day) in breaking down algal growths. There is some concern, however, about the tolerance level of aquatic life to copper sulphate.

Dredging of the lake to remove its silt load had not yet started during the course of this project and thus could not be evaluated for this report.

In summary, the impoundment management strategy implemented at Hennops Lake has included a combination of techniques, which commendably involves a suite of catchment, pre-impoundment and in-lake management techniques. Further attention may need to be given, however, to addressing the causes of the pollution problems occurring in Hennops Lake, which result from activities upstream in the catchment. These would include the management of soil erosion as a result of poor agricultural practices and construction activities in the catchment, as well as poor quality runoff caused by inadequately maintained sewer infrastructure.

In addition, a word of caution is needed with regard to the nutrient status of Hennops Lake. In the event that the turbid conditions in the lake are satisfactorily addressed, attention would need to be focused on reducing nutrient levels to prevent algal blooms. This is because nutrient levels in the water are sufficiently high to sustain algal populations, were it not for the turbid conditions.

4. EVALUATION OF CASE STUDY IMPOUNDMENTS - ZOO LAKE, JOHANNESBURG

4.1 Location and Catchment Characteristics

Zoo Lake is situated approximately 5 km to the north of the Johannesburg CBD in the suburb of Parkview, adjacent to the Johannesburg Zoo. The lake is a man-made impoundment with a surface area of 4,3 ha. The basic characteristics of Zoo Lake are shown in Table 4.1.

Table 4.1: Characteristics of Zoo Lake

Geographic Location	26° 9' S ; 28° 2' E
Elevation	1 610 m AMSL
Surface Area	4,3 ha
Volume	64 000 m^3
Mean Depth	1,0 m
Maximum Depth	2,0 m
Length	300 m
Width	100 m

The total catchment area of Zoo Lake comprises 432 ha, of which approximately 75% is made up of residential areas serving the higher socio-economic segment of the population. The remaining 25% of the catchment comprises park land (including the zoo). The catchment area extends from the Johannesburg and Kenridge hospitals in the south to Englewood Drive in the north and from Kildare and Pallinghurst Road in the west to Saxonwold Drive and the Parktown Convent School in the east (Figure 4.1). The lake is fed by stormwater from its catchment and washdown water from the zoo. Several small islands exist in the lake including the large central island.

There are two inlets to the lake, both situated on the south-eastern side of the lake. One of the inlets has been bricked up and only minor seepage of water occurs through this inlet. The other inlet is fed by a small pre-impoundment upstream of the main lake. The small pre-impoundment effectively acts as a silt trap and is equipped with a surface aerator to keep the water aerobic. Water exits Zoo Lake over a weir sited at the northern end of the lake, as well as via a valve

Tower, situated under a concrete jetty, which is also at the northern end of the lake. During heavy runoff from the catchment, excess water is diverted past the lake by means of a stormwater by-pass drain located on the south-western side of the lake.

Water from Zoo Lake discharges into a culvert, which in turn discharges into the Braamfonteinspruit. The Braamfonteinspruit feeds the Jukskei River which joins the Crocodile River north of Johannesburg. The Crocodile River flows into the Hartebeespoort Dam.

4.2 Dam History

Zoo Lake was built in the first decade of this century. Modifications and extensions to the stormwater drains and retaining walls at the inlet of the lake were carried out in 1937. An additional inlet from the pre-impoundment upstream of Zoo Lake was built in 1938. This inlet is still in use today, but the original inlet to the lake has been sealed. The fountain in the lake was designed and installed in

Figure 4.1: Zoo Lake Catchment

1939. The stormwater by-pass channel round the lake as well as the valve tower under the concrete jetty were built in 1946. The valve tower can be used to control the level of the lake. In 1983, the stormwater bypass channel was covered for most of the way with reinforced concrete slabs. In 1991, a small offtake to the local sewer was built to the west of the small pre-impoundment, allowing part of the stormwater flows from the zoo to be diverted from the lake.

4.3 Dam Use

Zoo Lake is used mainly for passive recreational purposes. Major activities that take place on and around the lake include rowing and cycling boats which are hired out by the Lions Club, picnicking/braaiing and strolling along the pathways and lawns surrounding the impoundment. Angling takes place, but this is mostly restricted to locals frequenting the lake. There are also two sports clubs next to Zoo Lake, the Zoo Lake Sports Club and the Zoo Lake Bowling Club, and a restaurant.

4.4 Water Quality Problem Description

In-lake water quality problems at Zoo Lake include bacteriological contamination and high concentrations of algae as a result of excess nutrients in the water. These nutrients are sourced from:

- polluted base flow from the zoo;
- polluted stormwater; and
- large populations of water fowl.

4.5 Existing Impoundment Management Strategies and Costs (1995)

4.5.1 Gunniting of Lake Banks and Island Shore

Aim of strategy: To reduce the nutrient load entering the lake from bird droppings being washed off the central island. This is an in-lake strategy addressing water use.

Date strategy implemented: Started April 1994.

Capital costs: R280 000.

Maintenance costs: None.

Other relevant information: A retaining structure was built on the island and guano was collected before gunniting in 1995. The maintenance operation is scheduled for winter when there are fewer birds. The gunniting of the island shores was completed in 1995. Guano was again removed during winter 1996.

4.5.2 Dredging of Pre-impoundment

Aim of strategy: To remove sediment and silt which is high in organic material and causes odours when it decomposes and which is re-suspended during floods when it is flushed into Zoo Lake, thereby increasing contaminant loads. This is a pre-impoundment strategy addressing the transport of contaminants.

Date strategy implemented: August / September 1994.

Capital costs: None.

Maintenance costs: R70 000.

Other relevant information: The dredged material was removed to a pit which had been dug and was buried. There were therefore no transport costs. This would have added approximately R50 000 to the cost.

4.5.3 Installation of Aerator in Pre-impoundment

Aim of strategy: To aerate the water in the pre-impoundment to prevent odours being generated by anaerobic sediments which are rich in organic material. This is a pre-impoundment strategy addressing the transport of contaminants.

Date strategy implemented: April 1994.

Capital costs: R50 000.

Maintenance costs: Unknown.

Other relevant information: There is a proposal to install an additional three aerators in the main lake at a later stage to perform the same functions as in the pre-impoundment.

4.5.4 Construction of Pre-impoundment Settler and Wetland System

Aim of strategy: To construct a pre-impoundment settler and wetland system to treat at source the high nutrient load (washdown water) from the Johannesburg Zoo. This a catchment strategy aimed at addressing waste production.

Date strategy implemented: Not yet implemented

Capital costs: Unknown.

Maintenance costs: Unknown.

Other relevant information: A detailed study conducted in 1994, indicated that treatment of the base flow from the zoo in a settler system, would reduce the level of nutrients in Zoo Lake itself. Additionally, modifications to the hydraulic loading of the lake, whereby polluted stormwater is diverted around the lake, and unpolluted stormwater is allowed to enter the lake to flush the system, were proposed.

4.6 Monitoring Programme – Key Changes

A comprehensive monitoring programme is already in place at Zoo Lake. Each inflow canal is monitored, as well as the inflow and outflow to the pre-impoundment and the outflow from Zoo

Lake. Additionally, a comprehensive range of water quality analyses is measured. Minor modifications were made to the sampling programme to facilitate evaluation of the management strategies. These were:

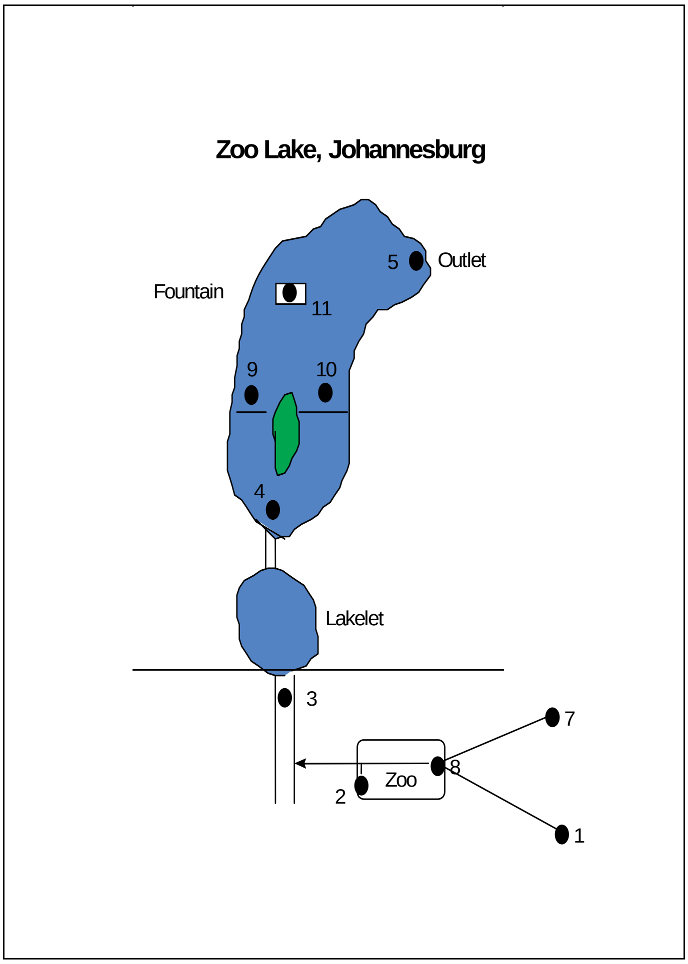
- Three additional monitoring sites:
  1. a site in the lake, on the eastern side of the island;
  2. a site in the lake, on the western side of the island; and
  3. a site in the lake, near the fountain.

- The suite of water quality analyses was found to be acceptable for chemical and bacteriological parameters, but chlorophyll *a* concentrations and algal identification were added.

The locations of the sampling sites are presented in Figure 4.2.

4.7 Water Quality Synopsis

In-lake problems at Zoo Lake include high concentrations of algae as a result of excess nutrients in the water. The management strategies in place are nearly all aimed at preventing high nutrient load water from entering Zoo Lake. In assessing these strategies it is necessary to evaluate the nutrient loading to the lake and the concomitant algal populations and speciation.



NB: Sampling site 6 has been abandoned

Figure 4.2: Sampling Locations at Zoo Lake

4.7.1 Nutrient Concentrations

Summary statistics for nutrient concentrations are presented in Table 4.2.

Table 4.2: Summary Statistics for Nutrients in Zoo Lake

Sampling Site :zl1	Mean	Median	Min	Max	95 th	Count
Ammonia	0.92	0.00	0.00	23.00	1.58	77
Kjeldahl N	2.75	1.80	0.00	26.00	12.53	70
Nitrite	0.19	0.05	0.00	3.80	0.79	62
Nitrate	2.31	1.80	0.00	10.50	8.19	62
Total Phosphate	1.02	0.50	0.00	14.00	4.66	70
Orthophosphate	0.31	0.10	0.00	7.60	1.10	77
Sampling Site :zl2	Mean	Median	Min	Max	95 th	Count
Ammonia	6.52	3.55	0.00	46.00	27.05	80
Kjeldahl N	12.08	8.20	0.00	130.00	35.95	72
Nitrite	0.97	0.37	0.00	20.00	2.90	62
Nitrate	4.77	2.90	0.00	52.50	12.85	62
Total Phosphate	2.39	1.20	0.00	53.00	4.07	72
Orthophosphate	0.74	0.50	0.00	5.80	2.01	80
Sampling Site :zl3	Mean	Median	Min	Max	95 th	Count
Ammonia	4.97	2.20	0.00	30.00	19.00	80
Kjeldahl N	8.55	6.40	0.00	40.00	28.80	73
Nitrite	1.03	0.52	0.00	6.40	4.34	62
Nitrate	5.80	4.30	0.57	37.00	13.98	62
Total Phosphate	1.38	0.99	0.00	11.00	3.67	72
Orthophosphate	0.73	0.55	0.00	7.90	1.82	80
Sampling Site :zl4	Mean	Median	Min	Max	95 th	Count
Ammonia	0.99	0.54	0.00	14.00	2.66	75
Kjeldahl N	2.86	2.40	0.00	14.00	7.22	74
Nitrite	0.27	0.16	0.00	2.20	1.00	62
Nitrate	2.88	1.60	0.10	41.00	6.38	62
Total Phosphate	0.99	0.54	0.00	14.00	2.66	75
Orthophosphate	0.18	0.15	0.00	0.70	0.54	80
Sampling Site :zl5	Mean	Median	Min	Max	95 th	Count
Ammonia	1.03	0.40	0.00	42.00	2.31	80
Kjeldahl N	6.94	2.80	0.00	250.00	11.49	72
Nitrite	0.10	0.05	0.00	0.90	0.60	62
Nitrate	8.95	0.50	0.00	448.00	20.57	62
Total Phosphate	0.86	0.50	0.00	9.00	3.41	70
Orthophosphate	0.12	0.10	0.00	0.60	0.40	80

Continued overleaf

Sampling Site :zl7	Mean	Median	Min	Max	95 th	Count
Ammonia	12.30	3.65	0.00	140.00	59.20	78
Kjeldahl N	13.83	6.20	0.20	142.00	38.80	67
Nitrite	0.72	0.29	0.00	13.00	2.21	60
Nitrate	4.23	2.35	0.00	38.00	23.53	60
Total Phosphate	2.27	1.20	0.00	16.00	7.68	70
Orthophosphate	1.18	0.79	0.00	6.40	4.35	78
Sampling Site :zl8	Mean	Median	Min	Max	95 th	Count
Ammonia	9.50	4.30	0.00	105.00	35.00	77
Kjeldahl N	11.52	7.00	1.20	56.00	42.40	67
Nitrite	0.56	0.31	0.00	3.80	1.90	58
Nitrate	5.18	2.50	0.00	117.00	9.58	58
Total Phosphate	4.64	1.20	0.00	210.00	4.94	69
Orthophosphate	1.02	0.70	0.00	4.70	3.34	77
Sampling Site :zl9	Mean	Median	Min	Max	95 th	Count
Ammonia	1.06	0.10	0.00	43.00	2.10	69
Kjeldahl N	3.05	2.40	0.00	17.00	9.00	66
Nitrite	0.09	0.04	0.00	0.60	0.55	52
Nitrate	2.28	0.40	0.00	27.50	21.33	52
Total Phosphate	0.90	0.40	0.00	28.00	1.65	66
Orthophosphate	0.11	0.07	0.00	0.70	0.42	69
Sampling Site :zl 10	Mean	Median	Min	Max	95 th	Count
Ammonia	0.43	0.00	0.00	3.20	1.80	71
Kjeldahl N	2.59	2.40	0.00	8.20	5.86	68
Nitrite	0.11	0.03	0.00	1.30	0.67	54
Nitrate	2.49	0.39	0.00	39.50	20.58	54
Total Phosphate	1.09	0.40	0.00	34.00	2.66	68
Orthophosphate	0.10	0.10	0.00	0.60	0.34	71
Sampling Site :zl 11	Mean	Median	Min	Max	95 th	Count
Ammonia	0.47	0.00	0.00	5.50	1.45	71
Kjeldahl N	2.58	2.40	0.00	8.40	6.96	69
Nitrite	0.09	0.04	0.00	1.00	0.54	54
Nitrate	3.66	0.40	0.00	104.00	22.58	54
Total Phosphate	0.76	0.40	0.00	6.40	3.07	67
Orthophosphate	0.11	0.08	0.00	0.60	0.40	71

NB. Figures are mg/ℓ

Inflow to Zoo Lake

The catchment is predominantly urban and thus the bulk of the water flowing into the lake represents typical urban runoff. There is however, a significant source of water and nutrients, which could be classified as a point source, and that is the zoo. Water used for the cleaning of cages, flushing and refilling of pools (such as seals and polar bears) and general runoff, all collect in a number of canals within the zoo, and water is discharged to a main canal, which enters Zoo Lake.

There are 5 sampling points upstream of Zoo Lake. Three sampling locations (1, 7 & 8) represent water entering the zoo. One sampling location (2) represents the water being discharged from the zoo. Sampling point 3 is located at the inlet to the pre-impoundment of Zoo Lake.

- Nitrogen Compounds

Water entering the zoo has a median ammonia concentration of 4.3 mg/ℓ and a median nitrate concentration of 2.5 mg/ℓ. The contribution from the zoo of 3.55 mg/ℓ and 2.9 mg/ℓ respectively results in a median concentration of 2.2 mg/ or ammonia and 4.3 mg/ℓ for nitrate entering the pre-impoundment. This decrease in ammonia and increase in nitrate is probably the result of biological conversion of ammonia from a reduced state to a more oxidised state. Nitrification by bacteria involves the oxidation of ammonia to nitrite and water, and further oxidation to nitrate. Time series plots for ammonia and nitrates are presented in Figures 4.3 and 4.4, for the sampling points 8, 2 and 3.

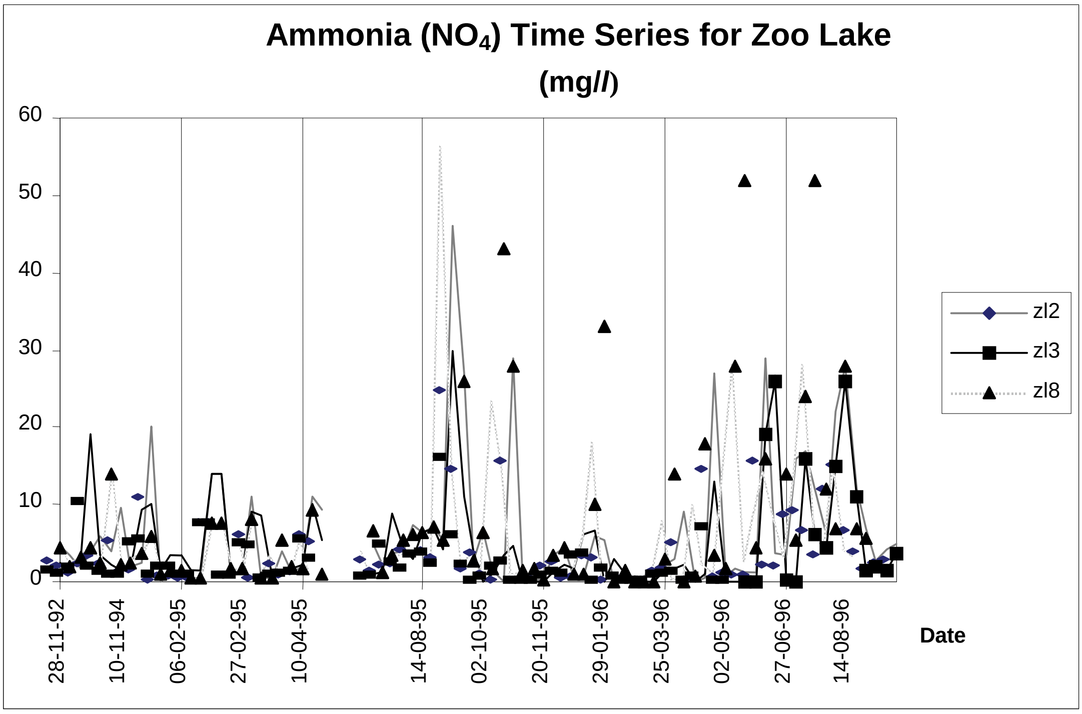


Figure 4.3: Ammonia Time Series Data for Stations 8, 2 and 3

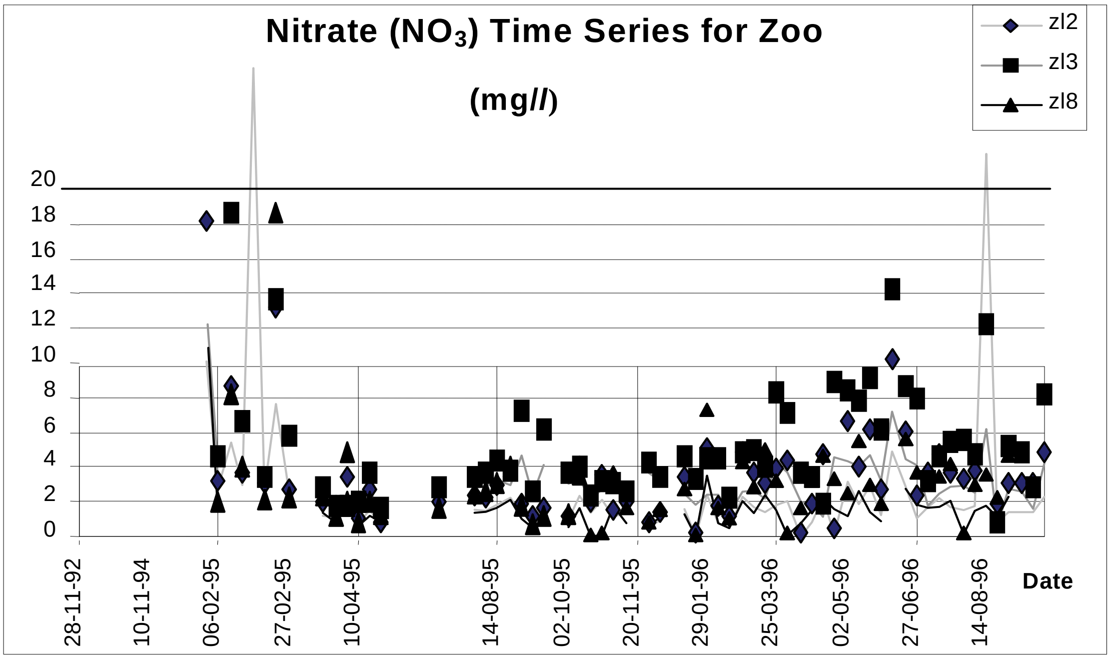


Figure 4.4: Nitrate Time Series Data for Stations 8, 2 and 3

Flow data was not available for the individual sampling localities but the total flow into the pre-impoundment is presented in Figure 4.5.

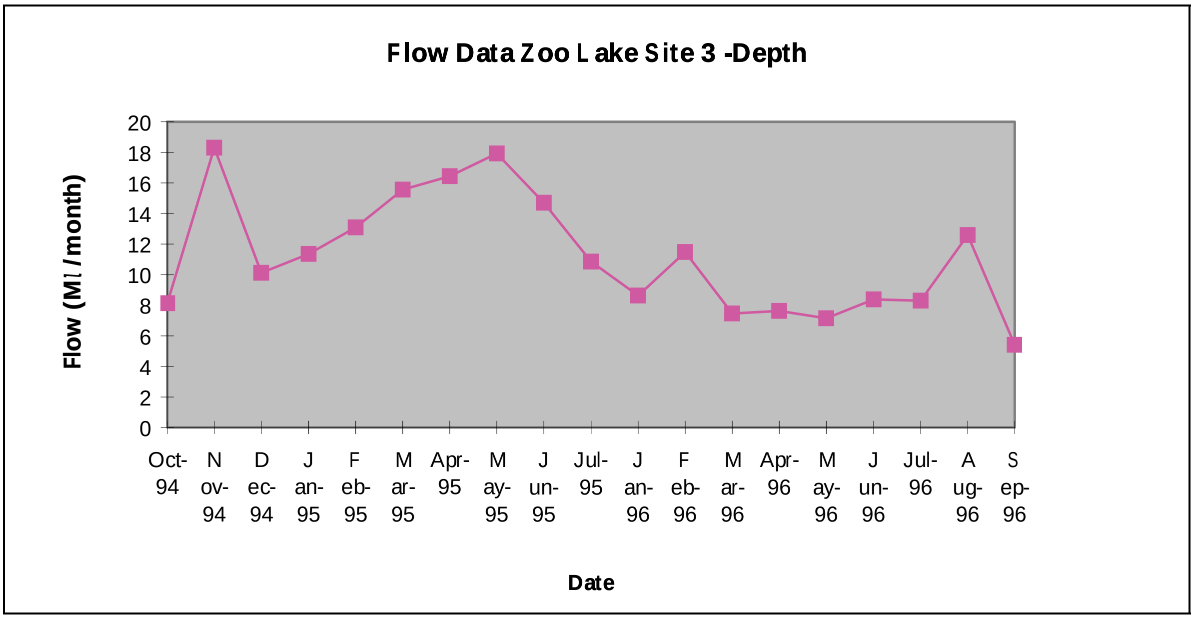


Figure 4.5: Flow Data for Zoo Lake Inflow

Flow volumes were calculated based on surveyed sections of the inlets and depth of water at times of sampling. Due to the nature of the sampling programme, monitoring was not undertaken during high flow conditions. One flood event was monitored in October 1994 by the project team. During this event maximum flow was calculated at 1 344 ℓ/s. The storm flow condition lasted 35 minutes. The integrated flow curve yielded a total flow of 1.4 Mℓ over the 35-minute period. The nutrient profile during the storm is presented in Figure 4.6.

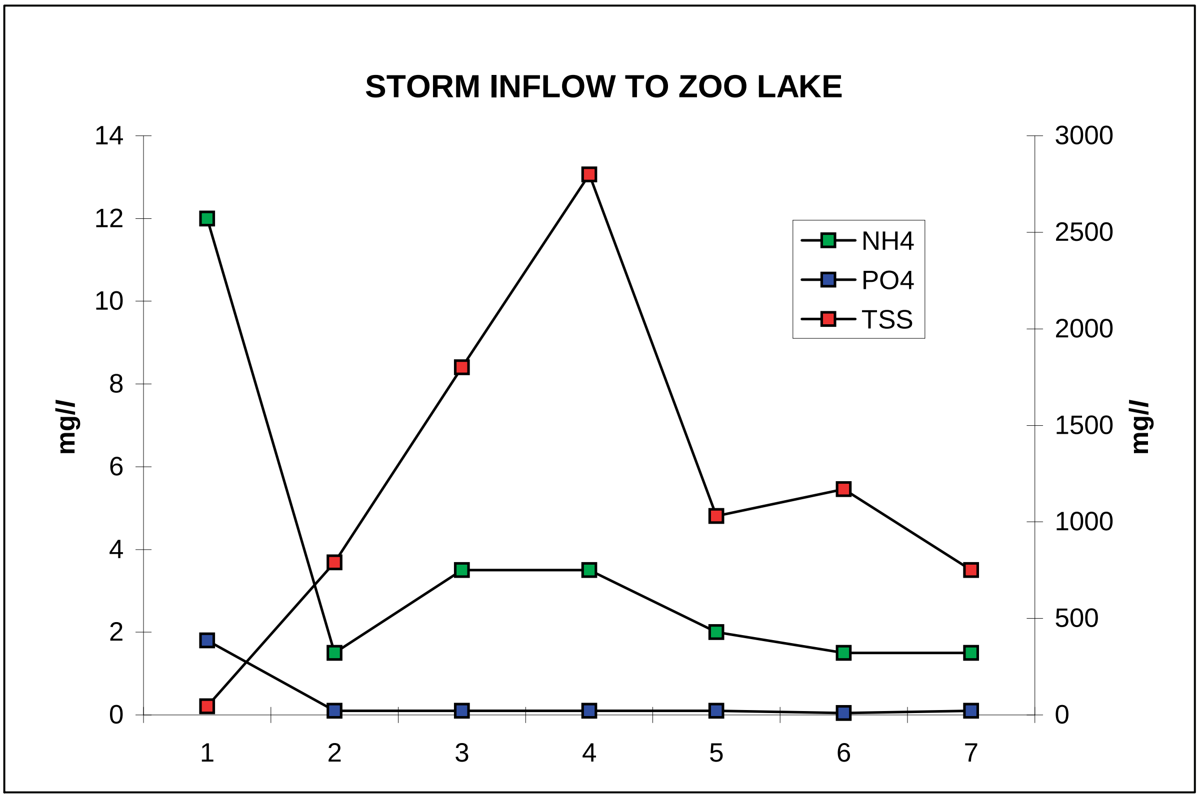


Figure 4.6: Nutrient Profile in Inflow to Zoo Lake during Storm Event

- Phosphorus Compounds

As far as phosphorus is concerned, the median total phosphate concentration upstream of the zoo is 1.2 mg/ℓ during the study period and for orthophosphate (PO4-P) 0.7 mg/ℓ. The concentrations found in the water discharged from the zoo were 1.2 mg/ℓ and 0.5 mg/ℓ respectively. The water entering the pre-impoundment had a total phosphate concentration of 0.99 mg/ℓ and 0.54 mg/ℓ for orthophosphate. The differences found are minor and not considered to be significant.

Time series plots for total phosphate and orthophosphate are presented in Figure 4.7 and 4.8, for sampling points 8,2 and 3.

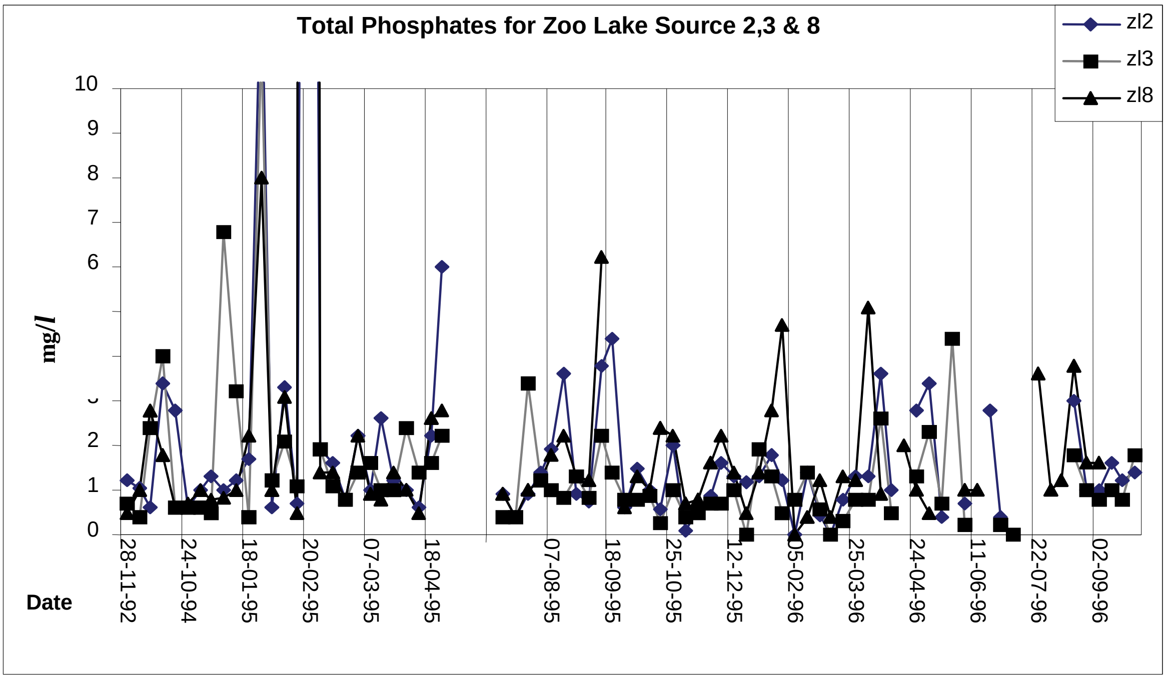


Figure 4.7: Total Phosphate Concentrations for Various Sites in Zoo Lake

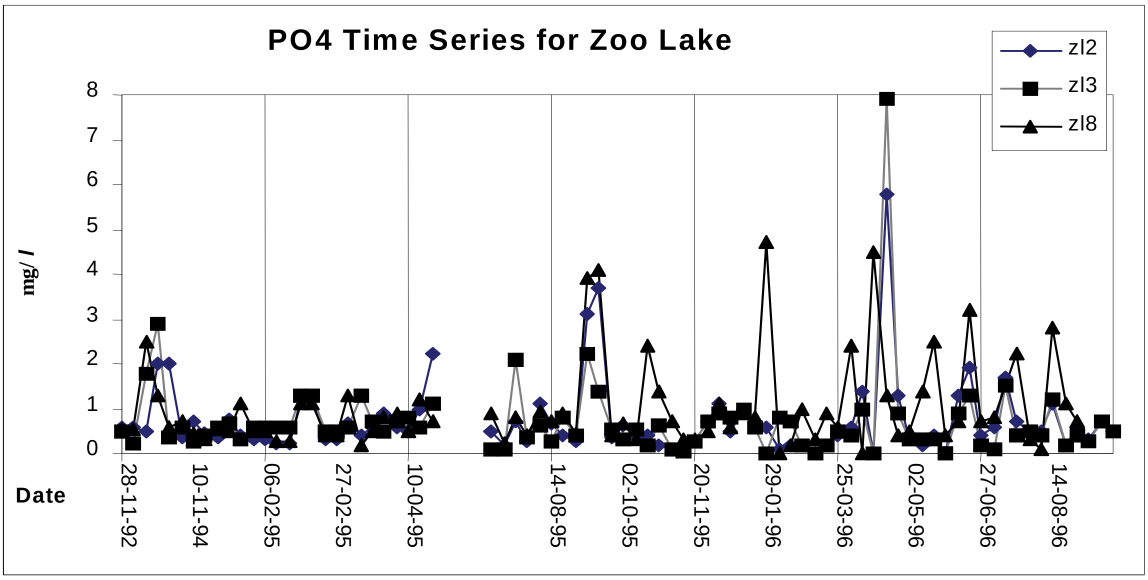


Figure 4.8: Orthophosphate Concentrations for Various Sites in Zoo Lake

The nutrient distribution for the whole system is presented in Figure 4.9.

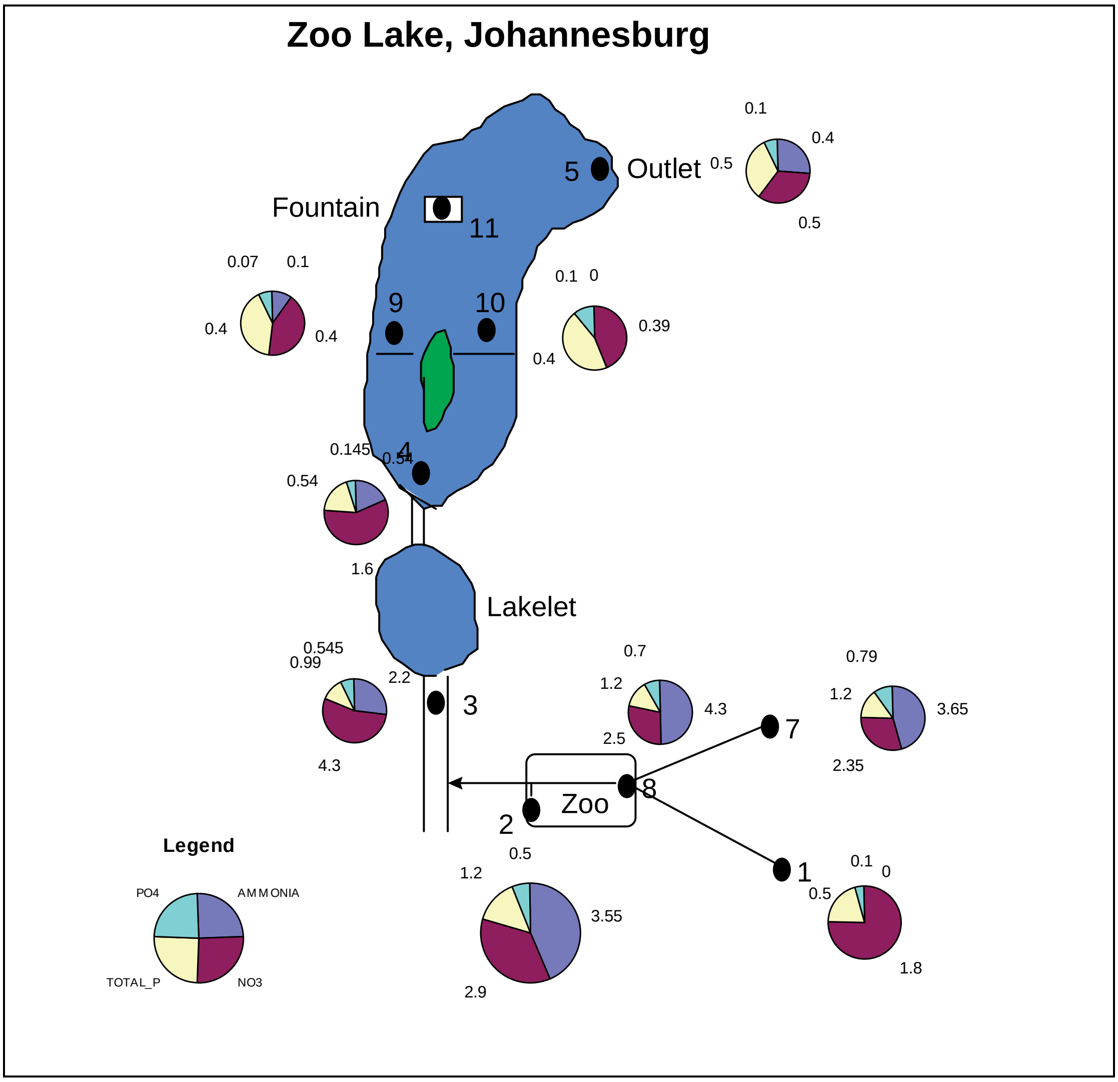


Figure 4.9: Nutrient Profiles for all Sampling Stations in Zoo Lake

Zoo Lake System

There are four key areas in the Zoo Lake system:

1. inflow to pre-impoundment (sampling site 3);
2. inflow to Zoo Lake (sampling site 4), equating to the outflow from the pre-impoundment;
3. in-lake water (sampling sites 9,10 and 11); and
4. outflow from Zoo Lake (sampling site 5).

- Nitrogen Compounds

Pre-impoundment System

Any changes in nutrient concentrations between sampling sites 3 and 4 are a result of processes acting within the pre-impoundment. The original purpose of the pre-impoundment was to act as an upstream settling basin. The ammonia concentration in the water entering the pre-impoundment is 2.2 mg/ℓ and this drops to 0.54 mg/ℓ after the pre-impoundment. For nitrates, the decrease is from 4.3 mg/ℓ to 1.6 mg/ℓ.

Zoo Lake

Within the lake, the following observations were made concerning the ammonia concentrations. The median inflow was 0.54 mg/ℓ and the median outflow 0.4 mg/ℓ. This is not considered to be a significant difference, and this is borne out by the 95 th percentile values of 2.66 mg/ℓ and 2.31 mg/ℓ for the inflow and the outflow respectively. However, the values recorded within the lake (sites 9, 10 and 11) show a decrease in ammonia concentrations. The median concentration was 0.1 mg/ℓ and lower. The 95 th percentile ranged from 1.45 mg/ℓ to 2.1 mg/ℓ. Time series data for sites 4, 5 and 11 are presented in Figure 4.10.

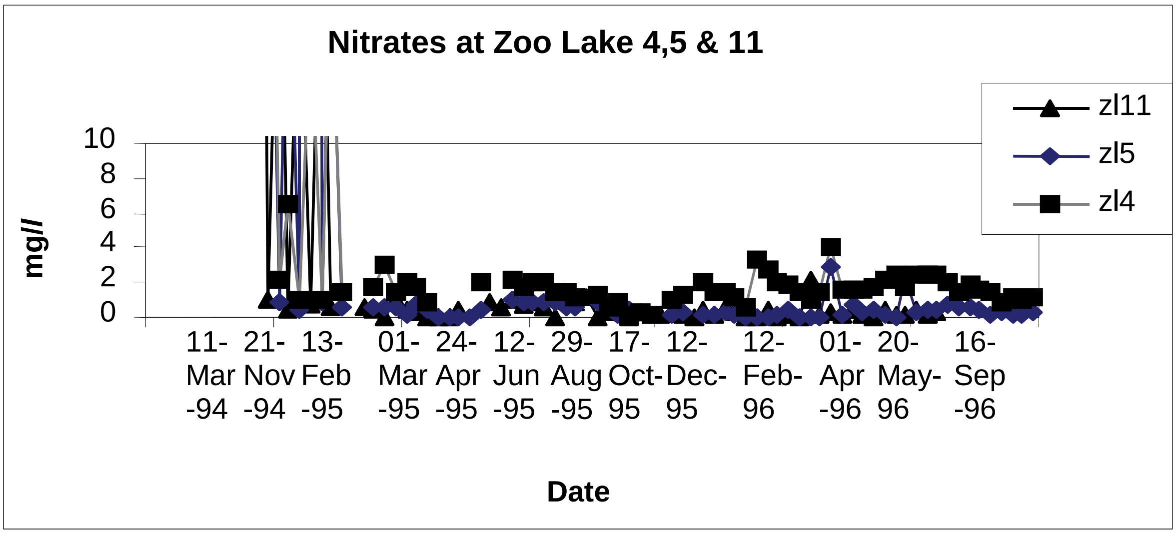


Figure 4.10: Time Series Data for Sites 4, 5 and 11

For nitrates there appears to be some assimilation within the lake as the median nitrate concentration of the inflow is 1.6 mg/ℓ and that for the outflow, 0.5 mg/ℓ. Within the lake, the median concentration is 0.4 mg/ℓ for all sites.

- Phosphorus Compounds

Pre-impoundment System

The total phosphate concentration of the water flowing into the pre-impoundment was 0.99 mg/ℓ. The outflow median concentration was 0.54 mg/ℓ. For orthophosphate the values recorded were 0.545 mg/ℓ and 0.145 mg/ℓ for the inflow and outflow respectively.

Zoo Lake

Within Zoo Lake there is some decrease in orthophosphate (PO_4-P) concentrations, with little or no change in total phosphate levels. For total phosphate, the median value for the inflow was 0.54

mg/ℓ, 0.5 mg/ℓ for the outflow, and 0.4 mg/ℓ within the lake. For orthophosphates, the median concentration in the inflow was 0.145 mg/ℓ and for the outflow 0.1 mg/ℓ. Within the lake the concentration varied from 0.07 mg/ℓ to 0.1 mg/ℓ. Figure 4.11 presents a time-series plot for orthophosphate for sites 4, 5 and 11.

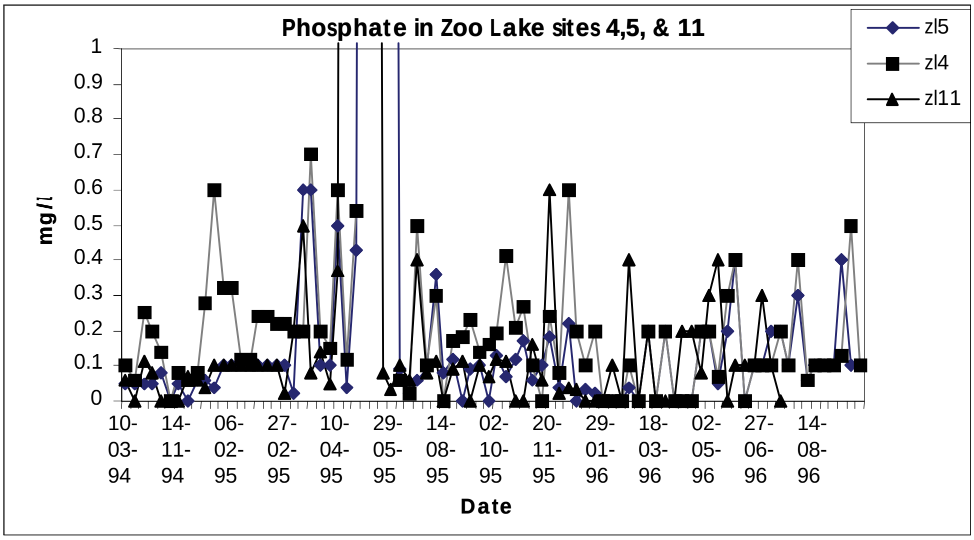


Figure 4.11: Time Series Plot for Phosphate for Sites 4, 5 and 11

4.7.2 Nutrient Loading and Algal Populations

Wetzel (1983) describes how the nutrient loading concept implies a relationship between the quantity of nutrient entering a water body and its response to that nutrient input. The effects of such a relationship can be expressed by some productivity index, such as chlorophyll *a* concentrations.

Before we consider the chlorophyll *a* concentrations within Zoo Lake, and the associated algal populations, it is necessary to revisit the importance of nutrients in algal production. The importance of phosphorus in algal physiology is important because phosphorus is generally the least abundant element of the major nutrients required for algal growth (Wetzel, 1983). It has also been shown that at phosphate concentrations of 0.05 mg/ℓ, there is a strong response from phytoplankton (Quibell, 1995).

However, in systems which are increasingly affected by urbanisation and where phosphates are added to the water by way of fertilisers, detergents etc., then end result may be situations where the lake or dam is nitrogen limited.

The ratio of nitrogen to phosphorus in the water is therefore important in determining the limiting nutrient for algal growth.

In terms of chlorophyll *a* being a measure of algal response to nutrients, the literature generally suggests that an annual average value of greater than 30 ug/ℓ represents a eutrophic lake, and that concentrations of algae at this level start to impinge on the recreational use of the lake.

Figure 4.12 presents time series data for chlorophyll *a* for the three sites in the lake (9,10 & 11). Figure 4.13 presents a schematic map showing the distribution of chlorophyll *a* in Zoo Lake.

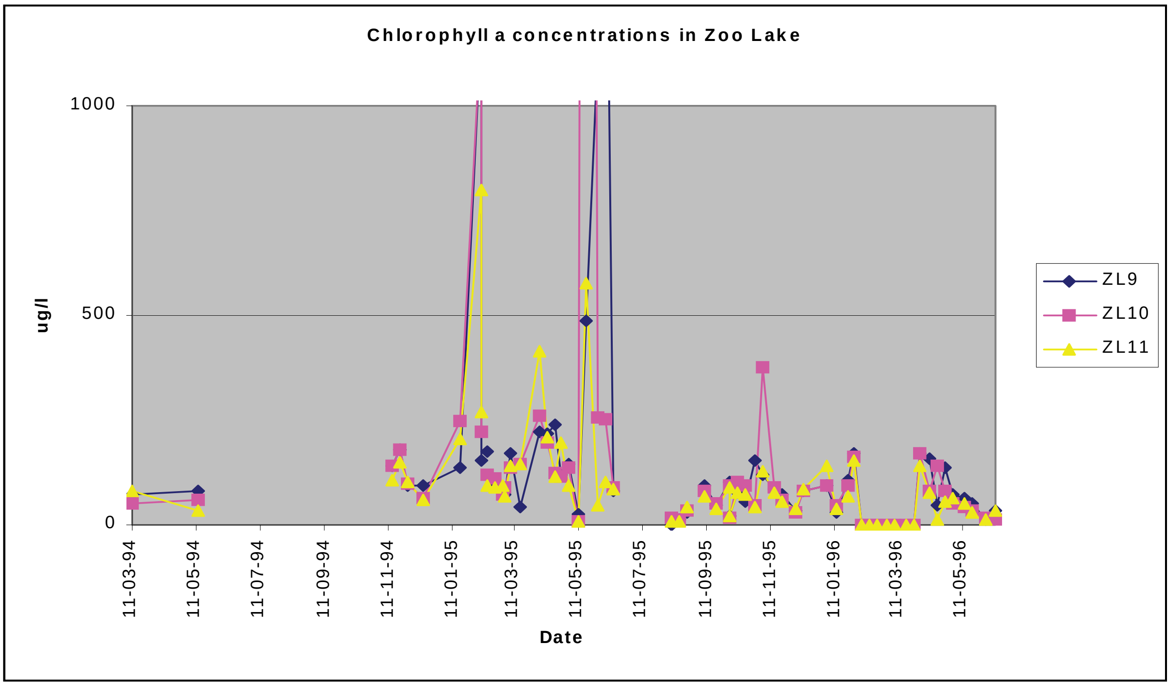


Figure 4.12: Time Series Data for Chlorophyll *a* for Three Sites in Zoo Lake (9,10 & 11)

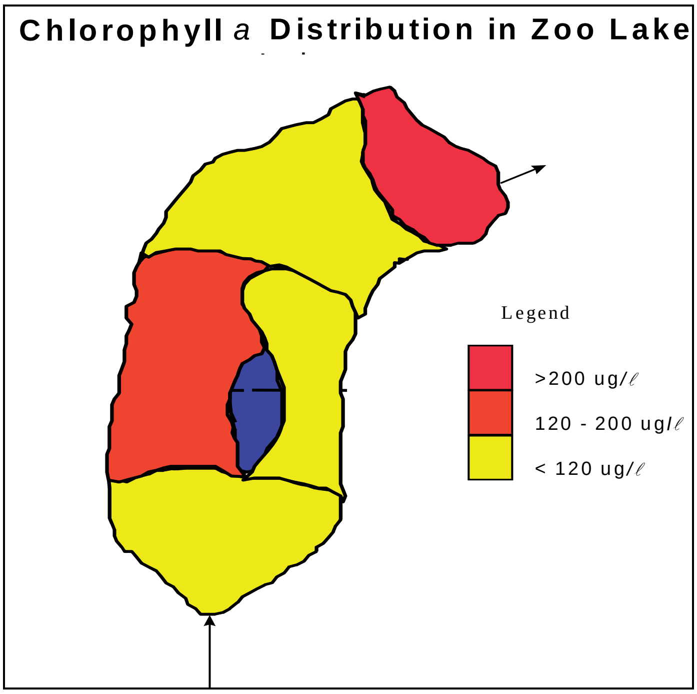


Figure 4.13: Schematic Map Showing the Distribution of Chlorophyll *a* in Zoo Lake

Summary statistical data for chlorophyll *a* is presented in Table 4.3.

Table 4.3: Chlorophyll *a* (in |g/ℓ) Statistics for Zoo Lake

Chlorophyll *a*	zl4	zl5	zl9	zl10	zl11
Mean	108.8	242.4	148.3	119.8	100.8
Median	77	65	87	88	77
Min	11	4	2	14	7
Max	271	4009	1826	1200	800
95 th	254.75	665.1	228.8	254.7	226
Count	14	63	53	55	55

It can be seen that on average, the level of chlorophyll *a* exceeds 30 |g/ℓ . It can be expected therefore, that such concentrations will cause nuisance conditions to prevail in the lake.

Algal distribution for site 10 in Zoo Lake is indicated in Figure 4.4.

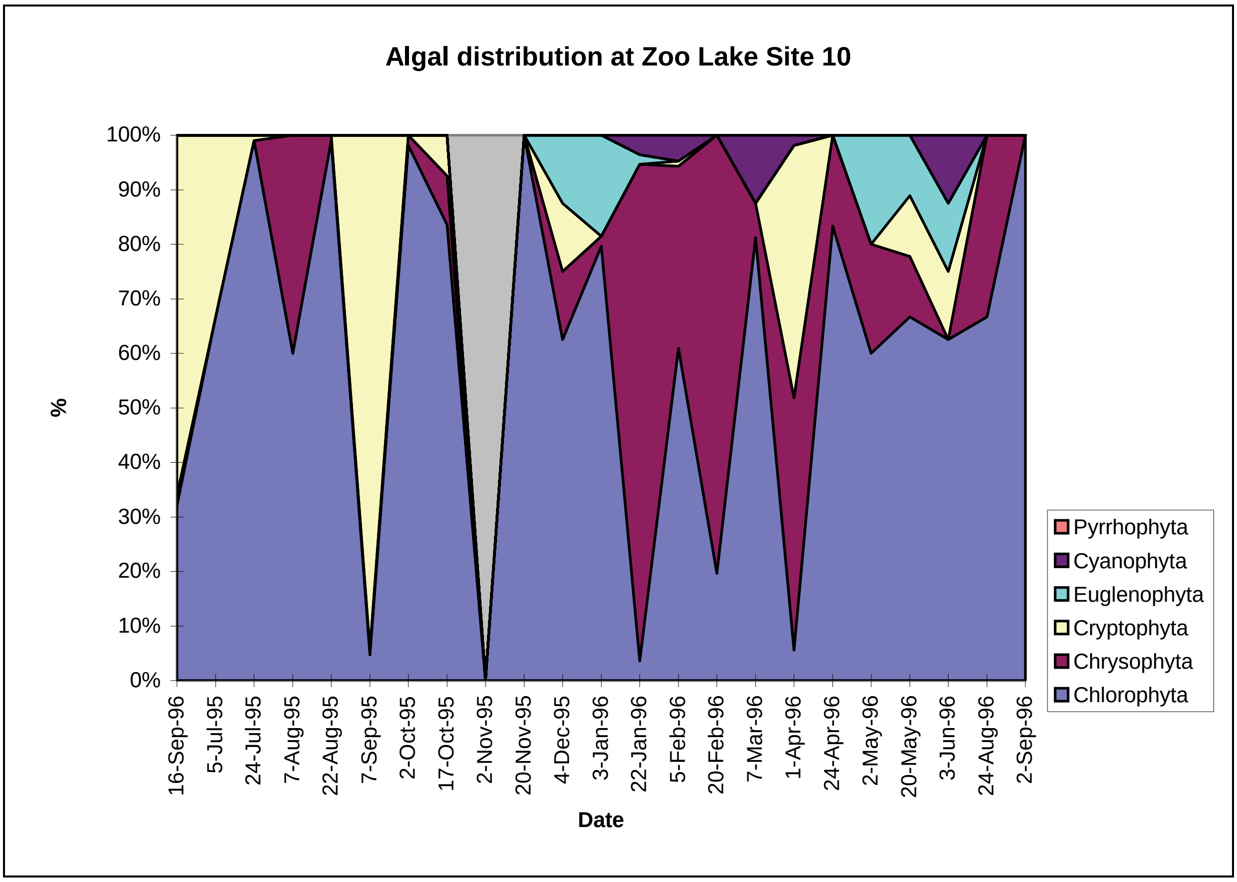


Figure 4.14: Algal Speciation in Zoo Lake

The results indicate that the dominant species of algae belong to the group *Chlorophyta*, but that, at times, specifically in summer, *Cyanophyta* are also present.

Cyanophyta are blue-green algae. Under eutrophic conditions, *cyanophyta* are one of the most common species of algae which bloom extensively. These blooms may cause severe problems such as tastes and odours, blocking of screens and filters, and some may be toxic. When blooms die off they can cause fish kills. As they decompose, they utilise oxygen in the water, thus depriving the fish of this life-sustaining factor. Blooms also interfere with the recreational use of the water body, impacting on fishing, boating and the aesthetic appeal of the lake or dam.

4.7.3 Bacteriological Contamination

Periodic high concentrations of *E. coli* have been observed in Zoo Lake. The summary statistical data for the Zoo Lake area are presented in Table 4.4.

Table 4.4: Summary Statistical Data for *E. coli* in Zoo Lake (counts/100 mℓ)

E coli	**zl4**	**zl5**	**zl9**	**zl10**	**zl11**
Mean	4 352	683	665	545	650
Median	1 600	200	500	350	300
Min	0	0	0	0	0
Max	38 000	7 777	2 800	2 400	4 700
95 th	17 200	1 500	1 660	1 735	2 800
Count	17	22	20	20	20

DWAF's Water Quality Guidelines for Recreational Use recommend a maximum permissible value of 126 counts/100 mℓ *E. coli* for full contact recreation and 1 000 counts/100 mℓ for intermediate contact recreation. The data for Zoo Lake indicates that high numbers of bacteria enter the lake but that some die-off occurs within the lake itself. The 95 th percentile indicates that water in the lake is not suitable for intermediate contact recreation.

4.7.4 Aesthetics

Aesthetic problems in Zoo Lake include the following:

- litter blown into the lake from the surrounding areas; and
- thick algal scums which become unsightly and on decay produce noxious odours.

4.8 Success of Management Strategies

An evaluation of the phosphate data for the Zoo Lake catchment identified that high concentrations of phosphate were present in all the streams, but that in the flow from the zoo, phosphate concentrations were higher. During the course of the research project, a number of teething problems were encountered with the newly installed settler and the wetland system, and by the close of the sampling of the project, the system was not yet fully operational. It is therefore impossible to undertake an evaluation of this management strategy, although it can be expected to contribute significantly to reducing both nutrient levels and bacteriological contamination in Zoo Lake once it is successfully commissioned.

Table 4.5 presents suspended solids data for the inflow to the pre-impoundment and the outflow to Zoo Lake. It can be seen that there is a slight reduction in the median concentration of suspended sediments within the pre-impoundment. The value decreases from 21.5 mg/ℓ to 18 mg/ℓ. Of particular importance, however, is that the maximum value for the outflow is significantly lower than the inflow (376 mg/ℓ inflow, 73 mg/ℓ outflow). Typically the higher load would occur during storm events and the current strategy is to bypass the initial storm events around Zoo Lake by way of an underground canal. This helps to reduce the sediment load to the lake itself. The fact that the pre-impoundment requires periodic dredging and that there is a need to use an aerator to mix in oxygen to the system, suggests that a portion of the sediment load is also being trapped in the pre-impoundment. The aerator was installed in order to reduce noxious odours from the anaerobic sediments.

Table 4.5: Suspended Sediment Data (mg/ℓ) for the Pre-impoundment at Zoo Lake

SUSPENDED SOLIDS	zl3	zl4
Mean	40.53125	20.5075
Median	21.5	18
Min	0.8	0.4
Max	376	73
95 th	176.4	44.65
Count	80	80

This strategy has thus achieved its goal and during the period of study was deemed to be successful.

Gunniting of the banks was only completed at the end of the project monitoring period and thus could not be evaluated. However, it could be expected to assist in reducing sediment loads and bacteriological contamination of the lake.

In summary, a suite of catchment, pre-impoundment and in-lake strategies has been implemented at Zoo Lake to address the poor water quality in the lake. It is somewhat premature to comment on the success of these management techniques as not all were fully operational by the end of the study period. Nevertheless, the study team is optimistic that appropriate techniques are being introduced to address the water quality problems at hand, particularly since Zoo Lake has a relatively small and thus more easily managed catchment.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The detailed survey of three case study impoundments reported in this Appendix was aimed at determining the success of the management strategies in place. The conclusions of the survey are presented in Tables 5.1 to 5.3.

Table 5.1: Results of the Detailed Survey for Jan Smuts Dam

Management Strategy and Purpose	Conclusion
Installation of 11 Aerators: To create an environment acceptable for development around the dam by mixing and aerating the dam water. By disturbing and introducing oxygen to the water, it is intended to change the predominant algal species in the dam from blue-green to the less problematic green species. This is an in-lake management strategy designed to address water use in the impoundment.	No complaints regarding odours and algal scums have been received from the public since installation of the aerators and therefore the management strategy was considered partially successful. Unfortunately, insufficient data was available to substantiate the change in algal species observed (to green algae) during one winter season, and thus the complete success of the management strategy cannot yet be gauged.
Walling of Southern Shoreline: To allow easier access to the water for recreation whilst preventing algae from being washed onto the shoreline, where it subsequently decays causing foul odours. The wall extends from the ash dump to the wastewater treatment works (which also has a walled front to the dam). This is an in-lake management strategy designed to address water use in the impoundment.	This strategy has also partially achieved its goal and during the period of study was deemed to be successful, although during high winds water could still be washed over the wall onto the shoreline.
Introduction of Fish: To introduce a new species of fish (kurper) for anglers at the dam which favours the consumption of algae. This is an in-lake management strategy designed to address water use in the impoundment.	The introduction of fish has probably improved the quality of fishing in the dam, as is evidenced by the large number of fishermen using the dam daily, but the success of their introduction to control algae could not be unequivocally quantified.
Litter Traps: To prevent litter entering the dam through the stormwater pipes. This is a pre-impoundment management strategy designed to address the transport of waste into the impoundment.	The litter traps were successful in preventing litter and other waste from reaching the dam except during periods of high flows when the lids of the traps were forced open.

Table 5.2: Results of the Detailed Survey for Hennops Lake

Management Strategy and Purpose	Conclusion
Chlorination of Inflow: To chlorinate the inflow water to Hennops Lake during winter, thereby reducing the bacteriological contamination of Hennops Lake to a level which would not be detrimental to watersport activities. This is a pre-impoundment strategy designed to address the transport of contaminants.	This strategy has achieved its goal and during the period of study was deemed to be successful, although its impact was confined to the low-flow winter period when recreational activities in the lake are fewer.
Upgrade Of Olifantsfontein Wastewater Works(1) And Construction of a Weir To Divert Sewer Overflows(2): 1. To expand the treatment capability of the wastewater treatment works from 38 Mℓ/d to 108 Mℓ/d, whilst improving the quality of effluent discharged to the Olifantspruit. This is a catchment strategy and is aimed at reducing the release of wastes to the river system. 2. To divert the polluted baseflow in the Kaalspruit north of Tembisa back into the main outfall sewer and on to the Olifantsfontein wastewater treatment works. This is a catchment strategy and aims at addressing the delivery of waste products.	Although there was a decrease in phosphate concentrations released to the Kaalspruit, there remains a significant residual phosphate load entering Hennops Lake.
Copper Sulphate Dosing: To treat and destroy algal blooms which accumulate in the lake particularly around the inlets to the musical fountain. This is an in-lake strategy and addresses the water use of the impoundment.	There was insufficient data to determine the success of this strategy during the study period. The dosing appears, however, to succeed in keeping the musical fountains operational.
Dredging: To remove silt from Hennops Lake which is filling the dam and reducing its potential for watersports and recreation. This is an in-lake strategy and addresses the water use of the impoundment.	Dredging had not started during the course of the study period and thus could not be evaluated.

Table 5.3 : Results of the Detailed Survey for Zoo Lake

Management Strategy and Purpose	Conclusion
Dredging of Pre-impoundment to Remove Trapped Sediment:. To remove sediment and silt, which is high in organic material and which causes odours when it decomposes and is re-suspended. This occurs during floods when material is flushed into Zoo Lake, thereby increasing contaminant loads. This is a pre-impoundment strategy addressing the transport of contaminants.	This strategy has achieved its goal and during the period of study was deemed to be successful.
Gunniting of Lake Banks and Island Shore: To reduce the nutrient load entering the lake from bird droppings being washed off the central island. This is an in-lake strategy addressing water use.	This strategy was only introduced towards the end of the study period and thus it is premature to draw conclusions on its effectiveness.
Installation of Aerator in Pre-impoundment: To aerate the water in the pre-impoundment to prevent odours from being generated by anaerobic sediments which are rich in organic material. This is a pre-impoundment strategy addressing the transport of contaminants.	Together with the dredging of the pre-impoundment, this strategy has been successful in reducing offensive odours associated with nutrient-rich sediments and algal scums in the lakelet.
Construction of a Settler and Wetland to Reduce the Phosphate Load to the Lake**:** To construct a pre-impoundment settler and wetland system to treat at source the high nutrient load (washdown water) from the Johannesburg zoo. This is a catchment strategy aimed at addressing waste production.	The settler / wetland system was not yet operational during the study period and thus could not be evaluated.

5.2 Recommendations

Jan Smuts Dam, Brakpan

The largely in-lake urban impoundment management techniques introduced at Jan Smuts Dam appear to have achieved some success in treating the symptoms of eutrophication experienced at the dam, since complaints about algal scums, odours and aesthetics have declined. However, high nutrient and chlorophyll *a* concentrations in the water of the dam persist suggesting that the causes of eutrophication still require attention.

Alternative management strategies which might address the causes of eutrophication and which are thus worthy of consideration include removing or sealing the nutrient-rich sediments in the dam, improving the quality of effluent discharging to the dam by the adjacent wastewater treatment works; and directing poor quality stormwater (e.g. the first summer rains) or flushing the impoundment.

A weakness of the management strategy adopted at Jan Smuts Dam was to introduce a number of management techniques simultaneously, which makes assessing the effectiveness of an individual technique very difficult. In addition, the need to continually collect and analyse relevant water quality data at the dam was undermined during the study period as a result of a lack of resources at the local authority. Where financial or human resources are constrained, alternative resources can be sought via the organisations and individuals making use of the impoundment, because these groups will benefit most from an improvement in the water quality of the dam.

Hennops Lake, Centurion

The management strategy implemented at Hennops Lake has included a combination of techniques which commendably includes a suite of catchment, pre-impoundment and in-lake management techniques. Further attention needs to be given, however, to addressing, in the long term, the causes of the pollution problems causing concern at the Hennops Lake. These problems result from activities upstream in the catchment. The focus should be directed at management of soil erosion caused by poor agricultural practices and construction activities in the catchment, as well as poor quality run-off caused by inadequately maintained sewer infrastructure.

In addition, a word of caution is needed with regard to the nutrient status of Hennops Lake. In the event that the turbid conditions in the lake are satisfactorily addressed, attention would need to be focused on reducing the nutrient levels to prevent algal blooms. This is because the nutrient levels in the water are sufficiently high to sustain algal populations, were it not for the turbid conditions.

Zoo Lake, Johannesburg

A suite of catchment, pre-impoundment and in-lake strategies has been implemented at Zoo Lake to address the poor water quality in the lake. It is premature to comment on the success of these management techniques as not all were fully operational by the end of the study period. Nevertheless, the study team is optimistic that appropriate techniques are being introduced to address the water quality problems at hand, particularly since Zoo Lake has a relatively small, and thus more easily managed catchment.

It is critical, however, that adequate ongoing water quality monitoring of Zoo Lake and its catchment continues in order that a proper assessment of the management strategies in the long term can be made.

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APPENDIX B

A LITERATURE REVIEW OF URBAN IMPOUNDMENT MANAGEMENT TECHNIQUES

EXECUTIVE SUMMARY

This literature review of urban impoundment management techniques provides context and adds further detail to the summarised information given in Chapter 7 of the Manual on catchment management, pre-impoundment management and in-lake treatment techniques. It also contains additional references, as well as a bibliography of texts, which may be referred to for more background on individual management techniques and common water quality problems typically encountered in urban impoundments.

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1. INTRODUCTION

Lakes and dams, by virtue of their definite boundaries, can be viewed as islands of water surrounded by land. However, in terms of biological, physical and chemical influences, they are not independent of the surrounding land (Kira, 1988). Periodic in-flows from their catchments enter lakes and dams, and they are usually drained by outflowing streams. Lakes and dams cannot survive without these inflows of water and the associated supply of matter and energy. Therefore, the in-lake dynamics of such systems are dependent on catchment activities, the natural environment, and man's influence on these.

In terms of inland water bodies, lakes and dams are more stable than rivers. This stability is reflected in the fact that water entering them generally stagnates to a certain extent, and any silt, nutrient or toxic substance tends to become trapped in lake sediments, or in the bodies of organisms (Kira, 1988). The continuous input over time of high levels of nutrients, leads ultimately to the eutrophication of dams and lakes. It can be seen, therefore, that lakes are sensitive to changes in catchment activities.

Changes in land use cause concomitant changes in the quality of water leaving the area as rain-induced runoff. Increased concentrations of suspended sediment can be expected from natural areas which have been deforested, cleared for construction or urban development or which have been opened for agriculture. Increased levels of nutrients can also be expected as a result of the addition of fertilisers to crops, the discharge of variously treated sewage effluent from urban areas, and from industrial effluent discharges. Toxic substances can be expected to originate from stormwater runoff from urban and industrial areas, from accidental spills from industries, and from effluent discharges from industrial and mining activities.

Pollution sources are divided into two broad categories:

- point sources; and
- non-point or diffuse sources.

The influence of either of these sources varies from impoundment to impoundment, but of the two, the most easily managed in general terms, are the point sources. Traditionally this is accomplished by permit allocations awarded to specific concerns, based on some set of standards or criteria. These criteria vary depending on the policy of water management pertinent to the particular region or country. In South Africa, the historic method has been to set general effluent standards. The approach now being adopted is to allocate certain loads to specific discharges, based on the ability of the receiving water system to assimilate the pollution load. This ensures that the site specific nature of water systems are addressed in the allocation of waste loads, and further ensures that some form of compliance monitoring is implemented. Generally however, it is relatively easy to manage these point sources, assuming that sufficient manpower and money are available for monitoring and enforcement.

The most difficult sources of pollution to manage, are the diffuse source contributions. Diffuse pollution has been defined in a number of ways. Traditionally end-of-pipe sources were defined as point, and everything else as diffuse (Novotny, 1988). An emerging trend in Europe and the US, is to add contributions from urban stormwater, construction site and feedlot runoffs, combined sewer overflows etc., to the point source category, so that permits are required. To a limited extent, this is occurring in South Africa. Non-point sources can therefore be defined as ground or surface water associated with diffuse land activities that ultimately cause a deterioration in water quality. This would then include urban runoff, residential septic tank systems, lawn discharges, and agricultural, mining and construction activities (Novotny, 1988).

Diffuse pollution and its water quality effects are costly. A study undertaken by the Conservation Foundation, found that the changes in water quality associated with erosion in the US, amounted to approximately $6 billion (Novotny, 1988).

The primary sources of water for diffuse pollution are rain, potable water used for garden watering, washing cars, etc., and industrial water used for washdown, cleaning etc. The influence of volume and concentration effects on river systems is variable and not necessarily related to high flow:high concentrations. In some cases, the low to medium flows may have a greater effect on water quality (Novotny, 1988). It is therefore important, that information on flows and water qualities is available, since without it, the linkage between water quality deterioration and pollutant loads is difficult to develop, and it may be difficult to confront the legal ramifications of a pollutant abatement programme which relies on enforcement (Novotny, 1988). Determination of input loading rates from tributary sources is therefore an essential component of mass balance studies on lakes and dams (Preston *et al.,* 1989).

In addition to the quality of the water entering lakes and dams from various sources, in-lake processes can also be expected to vary, depending on a number of factors. Figure 1 is a schematic diagram showing the interaction of factors which ultimately determine the composition, distribution and amount of biota, the rates at which nutrients are recycled, and the general productivity (trophic status) of a lake. This schematic is taken from Cole (1983).

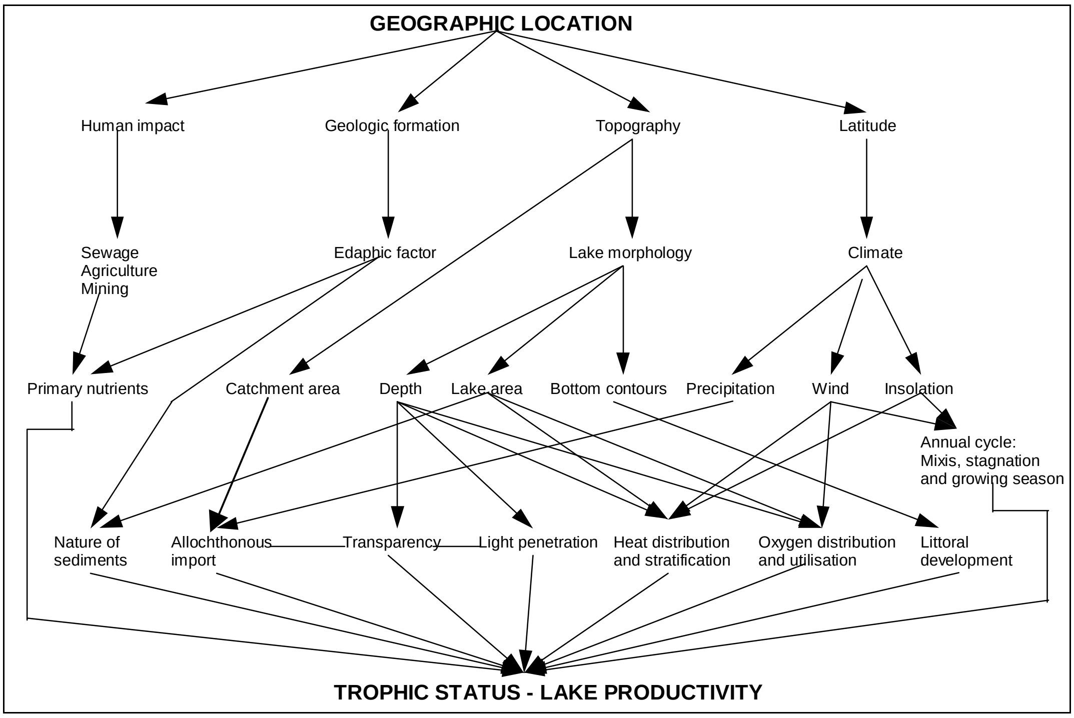


Figure 1 : Lake Dynamics

The highly complex interaction of factors within the impoundment further complicates the issue. For example, the depth of a lake influences transparency, light penetration, heat distribution and oxygen content of the water column. Therefore, anything which would influence depth, such as sedimentation, would, in turn, influence all these factors and ultimately affect the productivity of the lake.

Although no specific definition of an urban impoundment was developed for this research project, the applicable criteria used for selection can be used to arrive at a generic definition. For the purposes of this study, therefore, an urban impoundment was defined as a natural or man-made water body, greater than 4 ha in area and situated in a catchment which is clearly in a built up urban area. It is thus expected that water contributions to urban impoundments would be primarily from urban runoff, industrial and mining activities, point source discharges and other sources (which would include watering of lawns, etc.), but would not normally include significant contributions from agriculture.

The net result of these different sources of water can be expected to influence the functioning of the impoundment, and therefore its productivity. These influences, because of their very nature, tend to result in a negative change in lake function.

The prime focus should therefore be on the management of the whole system. Robbins *et al.* (1991) reported that in the US, most water utilities and local officials rely on a three-tiered approach that combines watershed controls, impoundment management and water treatment in order to achieve the best possible water quality. As a result of the problems associated with addressing diffuse source impacts, it can be expected that the primary management strategies for urban impoundments would be to look at pre-impoundment and in-lake options.

1.1 Common Problems Associated with Urban Impoundments

In broad terms, a number of problem areas can be readily identified as occurring in urban impoundments:

- eutrophication;
- sedimentation;
- bacteriological contamination;
- aesthetics; and
- serious pollution events.

Each of these problem types is described below.

1.1.1 Eutrophication

Eutrophication has been defined as the excessive supply of nutrients to water supplies, principally as a result of man's activities. In most lakes and dams, plant production is regulated mainly by the availability of nutrients. Should the level of nutrients within the lakes and dams be abundant, large growths of algae and macrophytes can be expected. It is these large growths of algae and macrophytes which manifest the extent of eutrophication and cause problems for users of lake waters.

Plants require numerous chemicals which are used to produce growth. These include major cations and anions and trace elements. Of these, the main nutrients which are implicated in eutrophication are phosphorus and nitrogen (Dallas, 1992). Both of these are required in the inorganic form, such as phosphates, nitrates, nitrites and ammonia. Organic forms are generally broken down by microbial action to the inorganic form (Dallas, 1992).

Phosphorus

Phosphorus (P) plays a major role in the structure of nucleic acids (DNA) and in energy storing molecules (ATP) in cells (Dallas, 1992). A significant portion of the phosphorus within a water system may be unavailable for use by plants because it is adsorbed onto suspended solids or bound to elements such as iron, aluminium and calcium (Addiscott, 1991).

A significant source of phosphorus in river systems affected by man's activities is treated sewage effluent.

Nitrogen

Nitrogen (N_2), although vital for life as a plant nutrient, does not command the attention that phosphorus does, because it is a naturally abundant chemical (Cole, 1983). Gaseous nitrogen requires a large amount of energy to convert it to a biologically readily available chemical. The breaking of the N_2 bond can require up to 36 ATP molecules (Cole, 1983). Only a few organisms are capable of this chemical transformation, as well as a few bacteria (including some blue-green algae).

The role of nitrogen in water bodies is its importance not as an abundant supply of nutrient, but rather as a limiting nutrient. As the ratio between nitrogen and phosphorus in the water changes, so plant populations also change. When phosphorus is added to an aquatic system, either by way of treated sewage effluent or by other terrestrial activities, nitrogen will become the limiting factor (Cole, 1983). A model developed for the Laurentian Great Lakes by Schelske (1975) showed that the addition of phosphorus accelerates the uptake of scarce nitrogen. Thereafter, the advantage for organisms able to fix nitrogen becomes the driving force, and a system which was dominated by diatoms, becomes dominated by blue-green algae (Cole, 1983).

The ratio therefore of N:P can influence the dominance of algal species. Should this ratio be manipulated without an understanding of the nutrient cycling within an impoundment, an undesirable change in species dominance could occur.

Algae

Algae are generally found in most freshwater systems. Their speciation and abundance are controlled by the amount of nutrients in the water, the clarity of the water and the climatic season (which influences the availability of light and the temperature of the water), as well as the rate of predation from organisms higher up in the food chain. Their ability to utilise sunlight as their energy source, and to combine water and carbon dioxide to produce starch and oxygen (photosynthesis), places them in the role as the basic building blocks in the aquatic environment. As such they play a vital role in the health of an ecosystem. Typically, the abundance and speciation of the algae is in equilibrium within the ecosystem.

The enrichment of water bodies with excess nutrients, however, tends to allow certain algal species to upset this equilibrium. The result is a shift in species dominance from a mixed system to perhaps dominance by one or two species, and an increase in abundance to a level where extensive blooms occur (Palmer, 1977). Water which is enriched or polluted with nutrients may allow the development of certain species of algae which are toxic to man or animals drinking it or living in it (Palmer, 1977). This shift in algal population dynamics can be expected to have deleterious effects on the other organisms within the water body.

For convenience, most of the algae of importance in water systems are grouped into four basic categories:

- green algae;
- blue-green algae;
- diatoms; and
- pigmented flagellates.

Green algae are grass-green to yellow-green in colour and typical species would be *Chlorella* sp. and *Pediastrum* sp. Blue-green algae, as their name implies, have a blue-green colour and are surrounded by a slimy coating. Typical examples are *Microcystis* sp. and *Anabaena* sp. The diatoms have a rigid wall containing silica which is sculptured with regularly arranged markings. An example is *Cyclotella* sp. The pigmented flagellates have the ability to move in the water and an example would be *Euglena* sp. (Palmer, 1977).

The overabundance of specific species of algae can have the following adverse effects on the use of the water :

- imparts tastes and odours;
- blocks filters; and
- toxic effects.

Taste and odour problems in water affect the suitability of water for treatment to potable standards, and the aesthetic appeal of the water body for recreational purposes. Green algae are less often associated with odour problems than blue-green algae (Palmer, 1977). Of the blue-green algae, *Microcystis* sp. and *Anabaena* sp. produce foul odours when they decay, which have been likened to the smell of rotting eggs.

Most algal species can block filters when present in large numbers. Sand filters are prone to blockages by diatoms and blue-green algae, and glass fibre filters are prone to blockages by green algae. However, although the various groups generally tend to block specific filters, each group can block any filter, irrespective of its make-up and size.

The development of toxic conditions as a result of algal activity is becoming more widely understood. The death of livestock as a result of toxic algae has been reported (Bruwer, 1984 and NRA, 1994). In the late 1970s cattle died as a result of drinking algal affected water at the Vaal Dam, and in 1989 a number of sheep and dogs died in England as a result of toxic algae in the water. These are but two examples, as reports of toxic algal presence have been gathered from all over the world. In 1989 alone, reports of toxic algae were received from Japan, Australia, Denmark, Sweden, Finland, Norway, Chile and Greece (NRA, 1990). The potential influence of toxic algae is considerable, and its control is discussed later in this literature review.

Rooted plants (macrophytes) can also proliferate to nuisance levels as a result of eutrophication. Examples of where such excess plant growths have occurred in South African impoundments include Wemmer Pan and Hartbeespoort Dam.

1.1.2 Sedimentation

Sediments in rivers and dams are derived from a number of sources, such as:

- erosion (both natural weathering and man-induced as a result of denudation);
- agricultural practices;
- construction ; and
- urban activities.

Within the framework of an urban impoundment, it can be expected that the site specific nature of the catchment will vary the volume of sediment originating from each of these sources.

The results of an increase in suspended sediment are:

- reduction in depth of water as sediment settles and builds up on the floor of the affected impoundment;
- smothering of submerged plants, thereby affecting the productivity of the lake;
- reduction in flood attenuation leading to increased inundation during high rainfall events; and
- trapping of nutrients and organisms in the sediment and thereby acting as a sink, from which resolubilisation and resuspension of nutrients can occur, given the appropriate conditions.

1.1.3 Bacterial Contamination

Bacterial contamination can come from a number of sources:

- wastewater treatment works effluent;
- direct contamination from human and animal faeces;
- blocked sewers and drains; and
- naturally occurring populations exploding as a result of man's activities.

The prime influence of increasing numbers of bacteria is on human health. Use of the water for drinking and recreation (e.g. fishing), can be negatively affected if the bacterial populations increase to above desirable levels.

Water abstracted for treatment to potable standards will generally remove bacterial contamination. Certain species of bacteria, however, such as *Cryptosporidium*, are difficult to remove and as such may cause health problems.

Water which is used directly, e.g. for direct drinking and recreation, is generally not treated, and therefore health problems may occur.

Bacteria which are implicated in health related issues are :

- faecal coliforms;
- coliphages; and
- protozoan parasites.

Inhalation of pathogens, during contact recreational activities such as swimming and water-skiing, can cause respiratory problems. Surface contact may cause eye, skin, ear and wound irritations. Many bacterial organisms occur naturally in the aquatic environment, and exposure may well be a hazard. However, water pollution conditions (such as increased nutrients and suspended material) can result in a large increase in numbers, leading to an increase in the health hazard (DWAF, 1993). Studies in the US have shown that the levels of *E. coli* (an indicator organism for the presence of faecal coliforms) in water show a high correlation with swimming related gastric illnesses (DWAF, 1993). This results in *E.coli* being used as an indicator organism for faecal pollution.

Coliphages are bacterial viruses which have been suggested as indicators of the presence and fate of human viruses in water. Coliphages require a coliform bacteria for replication, and therefore the presence of coliphages would indicate the presence of coliform bacteria (DWAF, 1993).

Relatively little is known about protozoan parasites in recreational water (DWAF, 1993), since they have been primarily identified in connection with domestic water use. An example of a protozoan parasite is *Cryptosporidium*. Infection occurs by ingestion of cysts or oocysts and disease takes the form of gastro-enteritis, diarrhoea, vomiting and anorexia (DWAF, 1993).

1.1.4 Aesthetics

Aesthetic problems in urban impoundments are usually secondary manifestations of the aforementioned underlying water quality problems. Some examples are:

- smells as a result of decaying algae, the release of hydrogen sulphide from bottom sediments, blocked sewers, dead fish; and
- visual changes as a result of litter, dog faeces, dense mats of algal scums, dead fish and suspended sediment.

1.1.5 Serious Pollution Events

Once-off pollution events cannot be placed into any one single category. A fire in a factory may not influence surface water systems until the fire brigade uses large volumes of water to douse the fire, and contamination of the water systems occurs. The type of contaminant can be highly variable.

1.1.6 Summary

Each of the problem areas outlined above, may give rise to a variety of specific problems which would negatively affect the use of the impoundment. The management of and solution to these problems can extend the usefulness of impoundments and increase their worth to the community. A typical example of successful lake restoration is described by Cole (1983):

" Restoration of sick lakes has claimed the attention of some limnologists, notably those who live in Sweden. A series of papers published in the proceedings (Verhandlungen) of the International Society of Limnology deal with the rejuvenation, restoration and recovery of Lake Trummen, Sweden. At the turn of the century Trummen was a shallow, brown water lake, low in nutrients, and oligotrophic. The diversion of sewage into the lake as the surrounding population increased changed the lake to such an extent that, by 1938, swimmers shunned it, although it had been a favourite bathing and boating site. Crayfish, microcrustaceans, molluscs, and some fish species disappeared. The emergent, littoral vegetation flourished and threatened to expand even more, while phytoplankton blooms, dominated by *Microcystis aeruginosa*, occurred in the open water. Sewerage discharge was stopped in 1959, but the black ferrous sulphide sediments remained atop the brownish bottom sediments of healthier days. The lake, however, did not respond to the removal of the pollution source, and a group from the Department of Limnology of Lund University began restorative methods. About 0.6 m of the nutrient-rich sediment was removed by suction dredging and deposited in separate settling basins. The hydrophytes that were encroaching upon the open water were removed in part; some areas were maintained to support the lake's rich bird population. Limnologists estimated that 50 tons of sedimentary phosphorus and 450 tons of nitrogen were removed via the dredging, and the bottom sediments ceased to be a source of harmful internal loading. Blue-green blooms no longer occur, light penetration is greater, and after many years absence, the swan mussel (*Anodonta cygnea*) has reappeared. The once doomed lake has become a valuable asset again to the nearby human community and serves as a model for many other restoration projects."

2. URBAN IMPOUNDMENT MANAGEMENT

The above example highlights one series of strategies aimed at addressing a particular problem. Not only are the problems themselves varied, but so are the strategies to address them. This literature review is limited to broad guidelines whereby the relative merits of particular strategies can be assessed. Short descriptions concerning the most notable of the strategies are presented, as well as the typical problem(s) which can be addressed with each strategy.

In terms of addressing problems, there are three main approaches:

- catchment management (watershed control);
- pre-impoundment treatment; and
- in-lake treatment.

2.1 Catchment Management (Watershed Control)

In essence the focus of catchment management is on addressing point and non-point sources of pollution.

2.1.1 Point Source Management

In South Africa, the Uniform Effluent Standards (UES) have been in place for over 20 years (V. d. Merwe, 1991). The UES approach aims to regulate the input of effluents into river systems by way of uniform standards. The net goal is to approach zero discharge of effluents. The standards are therefore set to treat contaminated effluents on the basis of BATNEEC (best available technology not entailing excessive cost).

This approach, however, has a number of drawbacks (V. d. Merwe, 1991). The prime focus is on the effluent and not on the receiving water. This ignores the fact that there may be more than one discharge, or that there may be high background concentrations in the river system. Also, the ability of the river system to assimilate pollutants is not taken into consideration. On the positive side, however, it is relatively simple and straightforward to apply in practice.

Although the application of the UES has ultimately led to a decrease in the rate of water quality deterioration (V. d. Merwe, 1991), deterioration of the resource has continued. It was realised that a different more advanced approach to water quality management was required. In 1991, the Department of Water Affairs and Forestry (DWAF) adopted a new approach based on the following principals (V. d. Merwe, 1991):

" The desired quality of a water resource is determined by its present and/or intended uses. This quality should be stated as a list of water quality objectives:

- It is accepted that the water environment has a certain, usually quantifiable, capacity to assimilate pollutants without detriment to predetermined quality objectives.
- The assimilative capacity of a water body is part of the water resource and, as such, must be managed judiciously and shared in an equitable manner amongst all water users for the disposal of their wastes.
- For those pollutants which pose the greatest threat to the environment, because of their toxicity, extent of bio-accumulation and persistence, a precautionary approach aimed at minimising or preventing inputs to the water environment should be adopted".

The Department's changed approach includes both the principles of Receiving Water Quality Objectives (RWQO) for non-hazardous pollutants, and pollution prevention for hazardous substances.

It can therefore be seen that the control of point source pollutants can be carried out via the use of regulations and permits. Monitoring of effluents therefore becomes an important factor. Monitoring programmes are used to gather information on water quality, how it changes over space and time and how it responds to management actions. A fuller review of aspects relating to monitoring programmes can be found in Chapter 5 of the Manual.

Problems can, however, be expected in the enforcement of regulations and permit requirements. Options available to improve enforcement, range from more vigilant policeing to involving members of the community to participate in the management of the system, and thereby employ a degree of self-regulation.

2.1.2 Non-point Source Management

Non-point source management is more difficult than point source management. The traditional design of urban stormwater systems provides for the rapid removal of stormwater via pipes and canals to, ultimately, a river reach (Ellis, 1989). This results at times in considerable, albeit transient, loads entering the system. Typically, high concentrations of sediments and nutrients, oils, grease, litter and others, enter the stormwater system. The net result is that any storage system downstream, such as an urban impoundment, will act as a settling and retention point for these pollutants. Effective management of diffuse pollution requires an integrated approach. Redesign of planning practices, regulations, and educational measures must be viewed as a whole.

As mentioned above, traditional stormwater systems act as conduits for diffuse pollution. Abatement methods or source control, identified in the US, have at their core the philosophy of separating clean and dirty water systems. Uncontaminated water is either allowed to recharge groundwater or is discharged to a river system in a controlled manner (Smisson, 1991). Contaminated water is collected and discharged to a sewage treatment works in a controlled manner when the works are able to cope with the extra volumes (Smisson, 1991).

An alternative approach to the aforementioned could be recharge to groundwater systems, by making use of soakaways in residential properties. Permeable pavements and the use of swales (shallow grass-filled ponds) allow water to be routed to either groundwater or surface water systems.

Contaminated runoff from roads and car parks will need to be treated before discharge. A system of small tanks can be used to store water temporarily for subsequent release to a sewer when flows permit.

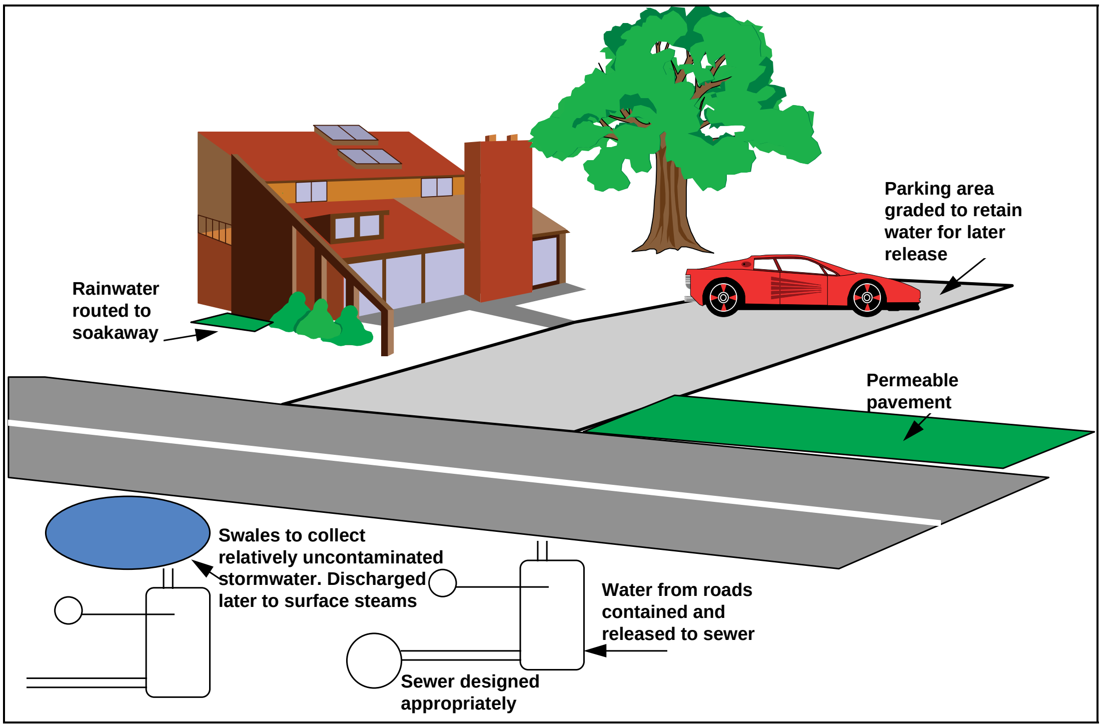


Figure 2 : Some Source Control Strategies (Smisson, 1990)

While these systems may be inappropriate in existing areas, new developments could incorporate such concepts from the outset. In existing areas, a number of strategies could be employed which would reduce the pollutant loads. Such options include:

- Routine cleaning of roads - an ongoing routine street cleaning programme, whereby the waste is removed to a proper facility, will reduce that amount of pollution which could find its way into the stormwater system.

- Proper disposal of household wastes such as paint, solvents, chemicals and oil, so that they are not poured down a street drain (Roesner and Hobel, 1992).

- Control of pesticides, herbicides and fertilisers.

Many people residing in urban areas are unaware of where stormwater systems drain to. Many people think that the stormwater systems eventually ends up in a wastewater treatment facility and therefore it does no harm to dispose of noxious chemicals down the stormwater drain (Roesner and Hobel, 1992). An education programme is needed in both established and developing communities. The people residing in the area must feel that they have some ownership over the stormwater systems and that it affects them directly if pollutants are allowed to enter the system.

This aspect of education is of particular relevance in those areas where informal settlements are developing. The socio-economic conditions prevailing within the community may mean that there is insufficient motivation for source control. Restructuring and development programmes may put funds in the hands of these communities, so that source control becomes a viable option. Education on its own will play a key role in reducing pollutant loads from such areas. The use of rainwater which has been stored for gardening and urban agriculture, could reduce the load of suspended sediments in the water in those areas where only a rudimentary infrastructure exists.

In terms of sediment in stormwater, a number of strategies need to be addressed:

- Developers should consider slopes and drainage paths in any new venture, from office development through to low-cost housing.

- Sediment control measures are needed at any development to retain sediment on the site.

- Soil stabilisation and re-vegetation need to be in place soon after construction has been completed.

Should improved planning practices, education and appropriate facilities not result in an improvement in stormwater quality, and should people be reluctant to pursue the concept of source control, then regulations will be required to address these issues.

Typically, however, and to the detriment of the stormwater systems, the responsibility for the various aspects which contribute to the diffuse pollution rests in a number of different hands. The cleaning of roads is the responsibility of one division of a municipality, maintenance of sewer systems that of another, waste disposal of yet another, and so on. This makes the overall control of the stormwater system difficult to manage. Additionally, stormwater systems may cross over municipal and regional boundaries.

Permit systems have been employed in the past, but these require enforcement, which places additional strain on restricted funds (Novotny, 1988). However, if any improvement in stormwater control is to be realised, legislation, regulations, permits, and penalties must all be employed in order to reach the end result of an improved water quality in the river systems.

2.2 Pre-Impoundment Management

The principle of pre-impoundment management is that poor quality water is treated in some way before being allowed into an impoundment. There are a number of strategies which can be used:

- construction of detention ponds;
- diversion of the poor quality water;
- dilution / flushing with better quality water;
- construction of a wetland system; and
- chemical treatment.

2.2.1 Detention Ponds

Detention ponds have been used extensively as a flood control measure (Akan, 1992). The recognition that diffuse pollution is a significant contributor to the deterioration of water quality led to the investigation of using detention ponds to improve downstream water quality. This is of particular relevance if the downstream impoundment has multiple uses, including recreation. By detaining runoff in a pond for a period of time, particulate matter is allowed to settle out and a better quality water is discharged.

The design of a detention pond is dependent on its function, i.e. removal of nutrients or removal of sediment. Toet *et al.* (1990) determined that for a removal of more than 50 % of suspended sediment, phosphorus and heavy metals from storm runoff, a 200 - 300 m^3 detention pond per hectare of catchment area would be required. Typical residence times within these small detention ponds is a matter of days. The following are broad characteristics of detention ponds:

- relatively low mean depth;
- surface release mechanism; and
- optimum size.

The removal of nutrients from the inflowing water is accomplished in a number of stages:

- biochemical conversion from the dissolved to the particulate form (mainly as phytoplankton); and
- sedimentation of the phytoplankton (Benndorf and Putz,1987) - this sedimentation is effected by naturally occurring precipitants and flocculants, as well as the planktonic structure within the detention pond.

The optimal management for detention ponds should take into account the following (Benndorf and Putz, 1987):

- The size of the dam should be designed for the optimum retention time and not simply for a long retention time.
- The mean depth should not exceed that of the euphotic zone, because of the dominance of photoautotrophic mechanisms which govern the phosphate removal. Phosphate elimination decreases exponentially with increasing depth.
- If the maximum depth of the dam exceeds the mixing depth and the depth of the euphotic zone, a strong vertical orthophosphate stratification will develop. This stratification gives rise to higher concentrations in the deep water layers, and lower concentrations in the shallower layers. Hence surface release becomes important.
- The bottom sediments will have to be removed over a period of time (normally every 5-10 years).

The efficiency of nutrient removal can be seen in the data presented in Table 1 below. The data is from an American detention pond system in the state of Minnesota (Oberts and Osgood, 1991).

Table 1: Removal of Nutrients from a Minnesota Detention Pond (Oberts and Osgood, 1991)

Site	TSS	DP	NO_3	COD
Inflow #1	240	0.25	0.66	185
Inflow #2	604	0.14	0.63	345
Inflow #3	269	0.29	0.72	196
Outflow	63	0.1	0.35	58

TSS = Total Suspended Solids; DP = dissolved phosphorous; NO_3 = nitrates; COD = Chemical Oxygen Demand. All values are mg/ℓ.

It can be seen that in some cases there was almost a 100 % reduction in concentration. As previously discussed, the main process is the conversion of the dissolved compounds to particulate matter (phytoplankton) which then settles.

Fiala and Praha (1992) found that inflowing concentrations of phosphate into a pre-impoundment (detention pond) upstream of Jesenice Reservoir, West Bohemia, were approximately 0.4 mg/ℓ. At the outflow from the detention pond, phosphate had dropped to 0.06 mg/ℓ. Within Jesenice Reservoir, the concentration dropped to 0.012 mg/ℓ. This represents a removal rate of 85 % in the detention pond, and 80 % in Jesenice Reservoir.

As a consequence of these phosphate concentrations, chlorophyll *a* values in the detention pond peaked at 230 ug/ℓ. At the outflow, the peak was 100 ug/ℓ. Within Jesenice Reservoir, the peak chlorophyll *a* concentration was < 50 ug/ℓ.

Cooper and Knight (1990) observed in Morris Pond, Mississippi, that nutrient removal efficiencies were 72 % for phosphate and 82 % for nitrate nitrogen over a five-year period.

Nearly all researchers have observed that sizing of the detention pond is the most important factor. A number of computer-based models (such as the POND system by Toet *et al.*, 1990 and Akan's "Design Charts", 1992) have been developed. Typical inputs required for such models are :

Solving the hydrologic storage equation:

$$i - q = \frac{ds}{dt}$$

where:
i = inflow rate;
q = outflow rate;
s = volume of water in storage; and
t = time.

Additionally the following information would be required:

- outflow structure from the dam (orifice-type or weir-type);
- peak inflow rates;
- duration of the inflow peak; and
- frequency of occurrence of peak inflows.

From this information, the optimal size of the pond can be determined to ensure optimum detention time within the detention pond, as well as the optimum evacuation time.

2.2.2 Diversion

Diverting poorer quality water away from impoundments reduces the external loadings to the impoundment. Diversion of treated sewage or industrial wastewater involves the construction of interceptor lines to convey the wastewater away from the affected water body for alternate disposal or treatment. Although it is easier to install diversion systems for point source discharges, runoff from non-point sources could be collected at a central point upstream of an impoundment and then routed to an alternate disposal or treatment site (Cooke *et al.*, 1993). The results of using such diversions, however, are varied. A number of lakes around the world have responded positively, such as Lake Washington, Lake Zurichsee and Lake Radasjon (Ryding and Forsberg, 1976). Some lakes have not responded as well as expected, such as Lake Norrviken, and others have not responded at all, such as Lake Schliersee (Ryding and Forsberg, 1976).

The diversion of secondary treated domestic wastewater at Lake Washington, resulted in a fast recovery. The resultant recovery was widely celebrated because it came at a time when there was much scepticism regarding the restoration of eutrophic lakes (Cooke *et al.*, 1993). Following the diversion, TP declined from 64 ug/ℓ to an equilibrium concentration of about 21 ug/ℓ, which resulted in a decrease in chlorophyll *a* from 36 ug/ℓ to an annual average of 7 ug/ℓ. Unfortunately, the fast, complete recovery of Lake Washington is atypical as will be described below.

At Lake Sammamish, domestic sewage and dairy wastewater were intercepted in 1968 (Welch and Patmont, 1980). Between 1970-1973 little recovery was observed. By 1975, winter epilimnetic (near surface) phosphorus content, summer chlorophyll levels and secchi disk depths had not changed significantly, but a substantial decrease in blue-green algae and phosphorus in summer were observed at overturn. It would appear that at Lake Sammamish, recovery did occur, but there was a delay in the onset of the recovery. One of the possible causes for this delay could have been urban runoff, which was not intercepted (Welch and Patmont, 1980).

One of the main conclusions to be drawn from the Lake Sammamish experience was the need for a holistic approach to nutrient management. The effect of the decrease in point source nutrient loading on water quality of the lake was only observed later because of the diffuse pollution emanating from urban areas which continued to supply nutrients to the lake.

A further cause of the delay in recovery was the internal loading of nutrients within the lake. This was sourced from the sediments and was also found in the biological populations within the lake. At Lake Ramsjon, diversion of wastewater reduced the in-lake P concentration from 0.252 mg/ℓ to 0.12 mg/ℓ (Ryding and Forsberg, 1976). Ryding and Forsberg found that if phosphorus release from the sediments could be reduced to "normal" levels, then an expected in-lake P concentration of 0.04 mg/ℓ could be released.

Internal loading becomes more important in shallow lakes, which urban impoundments typically are. This is principally because external processes can result in a release of phosphate to the photic zone, whereas in deeper impoundments, stratification tends to block the availability of phosphorus from the hypolimnion until the lake destratifies (Cooke *et al.*, 1993). Cooke *et al.* reviewed the results obtained in a study of nine shallow lakes (Sas, 1989) which indicated that a net annual release of TP was observed for the first few years after external loading was reduced, but diminished after about five years. This release was related to the sediment TP content which was in excess of 1 mg/g dry matter. The 1 mg/g level was considered to indicate saturation, and if the sediment concentration was above that level before external load reduction, the recovery of the lake would be slow (Cooke *et al.*, 1993).

Unless there is some additional treatment to the water diverted around an impoundment, diversion only relocates the potential for pollution to a downstream site. Thus, internationally, diversion is generally coupled with additional water treatment (AWT). This could involve a number of specific treatment options:

- chlorination;
- phosphate removal or elimination; and
- clarification.

As expected, the combination of these two management options increases the associated costs. Cooke *et al.,* (1993) estimated the costs for a number of lakes, where diversion and AWT had been implemented. Table 2 presents this cost data.

Table 2 : Estimated Costs (1990 US Dollars) for Diversion and Advanced Treatment to Restore Five Lakes (Cooke *et al.*, 1993)

Lake	Treatment	Year	Construction		Operation
			$ x 10 ^{6}	$ per capita	$ per capita
Washington	Diversion	1967	366	660	4
Sammamish	Diversion	1968	16.6	1362	12
Norrviken	Diversion	1969	148	352	16
Shagawa	AWT	1973	5.5	1102	77
Zurich	AWT	1975	86	605	115

If internal loading of P is expected to retard the recovery of the lake after diversion, additional in-lake measures may be warranted to hasten recovery. One such example was Lake Trummen in Sweden. Diversion of sewage effluent had no effect on the water quality of the lake over a ten-year period. However, subsequent dredging of the lake to remove one metre of sediment had a significant effect on the water quality (Cooke *et al*., 1993).

Diversion may not be feasible because of cost or the absence of a suitable alternate receiving water body. Additionally, stormwater may be difficult to collect and treat because of its diffuse nature, and the variety of source areas. The pressure from the local community may also affect the potential use of diversion as a strategy, since results may only be seen after several years, whereas in-lake strategies tend to operate on a shorter timespan. In these instances, good data is required to evaluate relative contributions from external and internal loads accurately. In certain instances the use of a non-steady state P model may be recommended.

2.2.3 Dilution / flushing

The technique of dilution/flushing can improve water quality within an impoundment in two ways; namely, the concentration of the limiting nutrient can be reduced, or the water exchange rate within the impoundment can be accelerated (Welch, 1982). The resultant effect on algae of dilution is to reduce the growth rate, and for flushing to increase the loss rate.

The use of dilution is only applicable where large volumes of low nutrient water are available. Generally, in urban areas, such sources of water are not available. With flushing, some improvement in algal biomass (i.e. a reduction) could be expected with moderate to high nutrient water, but the results would be less obvious in low nutrient water (Welch, 1982).

The effect of inflow concentration can be estimated from Vollenweider's model for the steady state phosphorus (P) concentration :

$$P = \frac{L}{Z(\rho + \sigma)}$$

where:

L is the area loading in mg/m^{2}/*a*;

Z is the mean depth in m; and

ρ and σ are coefficients for flushing and sedimentation in years.

If the flushing rate, ρ, is increased proportionally more than the area loading rate (L), the steady state P concentration will decrease (Welch *et al.,* 1980).

Starting in 1977, water from the Columbia River was diverted into Moses Lake, Washington (Welch *et al.,*1980). The Columbia River to Moses Lake nutrient ratio was 1:7 for total phosphorus and 1:18 for total nitrogen. The result was a reduced net inflow P concentration from 0.144 mg/ℓ to 0.1 mg/ℓ. The predicted in-lake concentration (from Vollenweider's model) was 0.063 mg/ℓ, but 0.075 mg/ℓ was actually measured. This was due to a substantial internal P loading within Moses Lake.

Although the P concentration within the lake was higher than predicted, the net decrease in inflow P concentration as well as the increased flow through the lake, resulted in a significant reduction in algal biomass. Chlorophyll *a* decreased by almost 80 % at times. In addition, blue-green algae comprised a lower percentage of the plankton crop after dilution (Welch *et al.*, 1980). The relatively slight decrease in inflow P concentration, however, would not give rise to a large reduction in algal species, and therefore, some other factor must have been influencing the algal growth. Welch *et al.* (1980) proposed a number of possible reasons for the decrease in algal biomass:

- chlorophyll *a* : carbon concentration could be limiting at certain stages;
- washout of algae as a result of the increased flow;
- greater dispersal of the algae as a result of movement of water within the lake; and
- the dilution water inhibited the growth of blue-green algae but not diatoms. This may be due to the dilution of allelopathic substances secreted by the blue-green algae, to a level at which diatoms can freely compete.

In Lake Talquin, Florida, Turner *et al.* (1983) found that during years with a higher than average flushing rate, phytoplankton productivity was 70 % higher than during average flush years. This would appear to have been due to an increase in reactive (available) phosphorus during this time. The inflow P concentration and the internal P concentration therefore, become the main influencing factors. It would thus appear that dilution would be better suited in this situation.

In terms of preferred flow dynamics, it would appear that for Moses Lake, a continuous low-rate inflow of water is preferable to a high-rate input for a relatively short period of time (Welch *et al.*, 1980). The rationale for this lies in the fact that at a high-rate input the P content will reduce quickly, and washout may occur, but once the system has stabilised, algal blooms will grow again within a relatively short period of time. This would hold true for most urban impoundments. However, should a major flood, with relatively low P concentrations, pass through an urban impoundment, much of the biomass may be physically removed, thus removing a portion of P loading to the system.

Dilution is frequently used synonymously with flushing as a restoration technique (Cooke *et al.*, 1993). For dilution, or nutrient reduction, to be cost-effective, the inflow water must be substantially lower in concentration than that of the lake. Effectiveness will increase as this difference increases. For washout of algal cells to be effective in the control of biomass, the flushing rate must be equal or close to the algal growth rate. The closer these are to each other, the more effective the strategy.

2.2.4 Wetlands

The increasing recognition of wetlands as treatment systems has opened up a number of new possibilities for the treatment of urban runoff. There are a number of different types of systems which are all grouped under the single term wetlands. This is principally because the very nature of a "wetland" system promotes diversity. "True wetlands must have one or more of the following three attributes:

- the land periodically supports predominantly hydrophytes;
- the substrate is predominantly undrained hydromorphic soil; and
- the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Hammer, 1992).

The variety of wetland systems includes marshes, bogs, swamps, and reedbeds. These systems need not be seen in isolation but may co-exist as an integrated system. Within such systems, there may be areas of dry land and areas of deep pools, but the main processes acting within the systems are dependent on water-sediment-vegetation interchanges.

Wetland systems vary in size depending on the volume of water available and the nature of the sediment on which the wetlands are based. Small depressions may become waterlogged for part of the year and are therefore characterised as wetlands. As a single unit, their effectiveness may be limited, but their importance lies in being part of the matrix of a treatment system.

There are two main types of constructed wetland:

- Free water surface wetlands - basins or channels are created in which emergent vegetation is grown. Wastewater is treated as it flows through the system.

- Sub-surface flow wetlands - where a gravel or sand media supports the emergent vegetation. The bed beneath the gravel is sloped and the water is encouraged to move through the gravel layer (Crites, 1994).

The main design criteria of free water surface (FWS) wetlands and sub-surface flow (SF) wetlands are presented in Table 3.

Table 3 : Design Criteria for Constructed Wetlands (Crites, 1994)

Factor	FWS	SF
Detention time (days)	5 to 14	2 to 7
Maximum BOD loading rate (kg/ha.d)	80	75
Water depth (m)	0.1 - 0.5	0.3 - 0.75
Area requirement (ha/m^3.d)	0.002 - 0.014	0.08*
Aspect ratio (length to width)	2:1 - 10:1	1:1

* SF wetland at Mesquite, Nevada.

It has been shown that some wetland systems can remove up to 70 % of the inflowing phosphorus (Cooke *et al.*, 1993). The main process appears to be P-deposition associated with iron complexes found with certain wetlands. In terms of nitrogen, 60-70 % was denitrified, 25-35 % was converted to ammonium, and 5-10 % assimilated (Cooke *et al*., 1993).

The main disadvantage of traditional wetlands is the size of land required. It can be seen from Table 3 that for a FWS system, the area required is between 0.002 and 0.014 ha/m^3.d. If one assumes that the other water quality criteria, such as BOD loading, are within specifications , a flow of 1ℓ/s requires an area of between 0.17 and 1.2 ha. The potential cost of land within an urban area, however, can be high.

Recently, the concept of source control wetlands has been developed. As described earlier in the section on non-point source control, pressure is being applied internationally to the development of stormwater control systems within new residential and industrial developments. In Adelaide, Australia, a 106 m gravel-filled trench will collect roof runoff from 15 cluster homes. The trench sustains a row of deciduous trees bordering the trench and provides recharge water to groundwater aquifers (Hopkins and Argue, 1994). Another system, also in Adelaide, utilises a swale/trench system to collect and treat runoff from a residential street (Hopkins and Argue, 1994).

The use of wetland type systems, which use biological, chemical and physical processes to treat urban runoff, will show significant improvements in water quality, but require large areas of land for development. If, however, additional uses for the wetland systems could be found (such as conservation and education), it may be economically viable to install these systems at some sites.

2.2.5 Chemical Treatment

In the US, recent changes to environmental policy have given a mandate to the Environmental Protection Agency (EPA) to enforce retrofitting of treatment systems to existing stormwater systems (Harper and Herr, 1992). Consequently interest has increased in developing rapid and efficient ways to reduce pollution in non-point discharges to surface waters. The ever-increasing cost of land has motivated the development of new systems which require little land, e.g. the development of chemical dosing systems.

The bacterial technology of wastewater treatment plants can be directly transposed to river systems. Chlorine dosing, of relatively small volumes of water, has been successful in the past. The main problem, however, is with soluble nutrients.

In 1986, a prototype system to treat runoff flow inside a sewer line was developed, using liquid aluminium sulphate, commonly called alum (Harper and Herr, 1992). Alum is an acid salt of aluminium which has been used in drinking water treatment, to remove phosphorus in wastewater for lake restoration projects, to improve water clarity, and to inactivate phosphorus release from sediments.

The addition of liquid alum to stormwater produces non-toxic precipitates of $Al(P0_4)$ and $Al(OH)_3$. The aluminium hydroxide ($Al(OH)_3$), is a gelatinous floc that attracts and absorbs phosphorus, heavy metals, suspended solids and bacteria (Harper and Herr, 1992). Results have shown that up to 85 % reductions in phosphates, 80 % reductions in metals, and 99 % reductions in coliform bacteria have been achieved. The net decrease of phosphate in Lake Ella, where such a system was employed, was from 0.023 mg/ℓ to 0.002 mg/ℓ.

The costs associated with alum dosing are as follows (in 1992, US dollars):

Capital (to treat 63 000 m^3)	$250 000
Chemicals	$6 800 / *a*

The concentration of dissolved aluminium was found to be on average 0.044 mg/ℓ between 1988 and 1990 (Harper and Herr, 1992). The EPA limit for sensitive aquatic species is 0.087 mg/ℓ.

2.3 In-lake Treatment

In-lake management strategies must be viewed as the treatment of the symptoms of water quality problems in most instances, rather than the cause. The development of large algal populations, the silting up of dams with sediment, and the subsequent potential release of nutrients from these sediments, are signs that catchment activities are negatively influencing urban impoundments and therefore may be affecting their desired use.

There are a number of strategies which can be employed to restore impoundment systems:

- biological;
- chemical; and
- physical.

2.3.1 Biological Control

Grass Carp

The biological control of *Potomageton pectinatus* has been researched world-wide since the 1970s. Initial studies indicated that the Chinese grass carp (*Ctenopharyngodon idella*) could be used to restrict the growth of this submerged plant (Woods, 1981). However, at the time little information was available concerning the breeding habits of the fish. Breeding in captivity was difficult and appeared to be temperature dependent (Bates and Hentges, 1976)

In South Africa, the biological control of *P. pectinatus* using *Tilapia rendalli* was investigated in Germiston Lake in 1973. During the summer, this fish successfully controlled weed infestation at densities of 1 fish/m^2, but in winter, the fish died. This was a result of the low water temperatures (average 10ºC). In Germiston Lake, massive fish kills occurred when the temperature dropped to 14ºC (Schoonbee, 1991).

Following these trials, attention was focused on a fish that could survive low winter temperatures. The Chinese grass carp was selected as a potential control agent and was introduced into Germiston Lake in 1982 (Schoonbee, 1991). Five thousand juvenile fish were introduced into enclosures for 6 weeks for acclimatisation. The fish were sourced from the Umtata Fish Hatchery and each weighed approximately 27 g. The stocking density was 85 fish/ha (Schoonbee, 1991).

In 1989, the Transvaal Provincial Administration's Division of Nature Conservation imposed restrictions on using the carp to control the weeds. This was resolved when triploid (sterile) carp became available from Arkansas in the US (Schoonbee, 1991). The fish were imported as fingerlings (2 g) and reared in open hatcheries at Hartbeespoort Dam until they had grown to 89 g when they were subsequently released into Florida Lake in Roodepoort.

Results for Germiston Lake indicated that the biomass of *P. pectinatus* declined considerably within a year after the introduction of the grass carp (Schoonbee, 1991). It was also found that survival rates were good but regular monitoring would be required to detect any decline in population, so that more fish could be introduced to control the plant. It was found that for Germiston Lake, fish growth was considerable. Re-capture of fish after 298 days showed an average daily increase of 3.9 g/d and after 436 days, 10.18 g/d (Schoonbee *et al.*, 1984).

One aspect which needs careful consideration, however, is the stocking density of the fish. A balance must be maintained between the plant biomass and the number of fish, for the system to sustain itself. This will ensure the optimal success of the strategy. Until the introduction of fish into Germiston and Florida lakes, stocking densities were based on experimental ponds (Venter and Schoonbee, 1991). The success at Germiston Lake (85 fish/ha) led to a reduction in the stocking density in Florida Lake (35 fish/ha). The results for Florida Lake indicate a similar success to that found for Germiston Lake (Venter and Schoonbee, 1991).

A comparison between the two lakes showed that there was very little difference between the normal grass carp and the triploid variety's ability to control the plant (Venter and Schoonbee, 1991).

The introduction of grass carp has demonstrated that it successfully controls *P. pectinatus*, but there are disadvantages. These are:

- The discrepancy in the ambient nutrient concentrations in lakes where the fish was introduced. Some researchers have observed a slight increase in nutrients without any concomitant increase in phytoplankton production which may be a result of the binding of the nutrients to sediments (Lembi *et al.*, 1978). Other researchers found that blue-green algal populations increased (Mitzner, 1978). At Florida Lake, the chlorophyll *a* concentrations have increased progressively over time (Venter and Schoonbee, 1991).

- The release of nutrients may lead to an increase in benthic diversity which would lead to a greater diversity of fish utilising other food sources (Venter and Schoonbee, 1991).

- The reduction in weed biomass may negatively affect bird species which utilise the plant for nesting and food (Venter and Schoonbee, 1991), but the reduced protection for smaller fish may lead to an increase in birds feeding on fish, such as cormorants (Venter and Schoonbee, 1991).

- The introduction of fish could lead to the introduction of bacteria and viruses, which may affect the grass carp or other fish.

Bothriocephalus gowkongensis was introduced into the Transvaal Provincial Fisheries Research Station by imported grass carp which affected the common carp, *Cyprinus carpio* (Schoonbee *et al.*, 1984).

Biomanipulation

The term 'biomanipulation' has been defined as the management of aquatic communities by controlling natural populations of organisms (Shapiro and Wright, 1984).

The traditional approach of limnologists to the concept of lake ecosystem structure was oriented towards the food chain concept:

nutrients → phytoplankton → zooplankton → fish.

Fish, however, were not considered as a factor which could affect water quality (Gophen, 1990). Consequently, most efforts to reduce the detrimental effects of eutrophication have focused on controlling nutrient additions (Gophen, 1990).

The role of fish however, as a potential method to improve water quality has been researched over a number of years but it is only recently that it has been considered on a large scale. Work has shown that mosquito fish reduce rotifer and crustacean zooplankton, thereby leading to increases in algal populations. It was suggested that increasing the fish populations may lead to a decrease in phytoplankton. The manipulation may take a number of forms:

- reduction of fish populations; and
- selection towards phytoplanktivorous fish.

The reduction in fish populations has been shown to lead to an increase in larger zooplankton (zooplanktivorous fish have been shown to favour larger zooplankton), a reduction in primary production, an increase in water transparency and a decrease in phosphates and nitrates (Gophen, 1990).

Shapiro and Wright (1984) used rotenone to eliminate Round Lake, Minnesota's fish populations. The lake was subsequently stocked with bluegill, largemouth bass and walleye. After this re-stocking, water transparency increased, chlorophyll *a* decreased, zooplankton densities decreased although the mean size increased, and nutrient concentrations decreased. It has been shown that the changes in the zooplankton not only affected the phytoplankton, but also due to their ability to assimilate nutrients at night from the epilimnion and to excrete these nutrients back into the whole water column, resulted in a net downward transfer of nutrients during diurnal migration (Gophen, 1990).

Despite the potential for piscivore manipulation, there may be some limitations:

- improved water quality may only be seen when planktivore yields are reduced to unacceptably low levels (McQueen *et al.*, 1986); and
- certain impoundments may be dominated by large deep-bellied fish which are not available to gape-limited fish such as the large mouth bass (Gophen, 1990).

The selection of planktivorous fish has also received attention (Gophen, 1990). Silver carp have been used in field trials and were shown to reduce blue-green algae and total phytoplankton biomass (Kajak *et al.*, 1975). However, some researchers have shown that silver carp stimulated phytoplankton and became zooplanktivorous during summer (Gophen, 1990).

Leah *et al.* (1980) found that in some instances it may not be feasible to manipulate fish populations. Other factors, such as the flushing rates of impoundments, may stimulate the growth of a less palatable alga, thereby reducing the effectiveness of fish control.

McQueen (1990) proposed that in shallow lakes, fish removal would result in a decrease in turbidity, which could be associated with an increase in dense macrophyte populations. This would obviously affect the use of the impoundment for recreational purposes such as rowing and motor-boating.

2.3.2 Chemical Control

Algal Control using Decomposing Barley Straw

Problems associated with the development of large blooms of potentially toxin-producing blue-green algae, can affect the use of an impoundment, particularly where the water is used directly by the public and animals. In the UK, the presence of decomposing barley straw in water was shown, both in the field and the laboratory, to reduce the growth of a range of algal species (Newman and Barret, 1993). The mechanism by which growth inhibition occurs is largely unknown. There are, however, general conditions required for this technique to have a beneficial result:

- the maintenance of aerobic conditions in the straw; and
- the development of a diverse microbial population leading to decomposition of the straw (Newman and Barret, 1993).

The original hypothesis, when this technique was first discovered, was that the microbial community would obtain most of the nutrients required for growth from the surrounding water column (Newman and Barrett, 1993). In addition, an alternate source of food for other animals in the food chain, such as plankton and fish, which utilise the nutrients, would develop.

Subsequent research, however, indicated that the main process was the inhibition of the growth of algae by a factor, at present unknown.

The anti-algal factor is produced in increasing amounts over approximately six months from the commencement of the rotting process, approximately one month after soaking in water (Newman and Barret, 1993). The fact that there is no difference in this time if the straw is powdered or left intact, and that all algal inhibiting activity stops if the sample is autoclaved, indicates that the process is driven by microbial decomposition of the straw.

Electron microscopy of the straw showed that initially there was a diverse bacterial population (in high numbers) but once the algal inhibiting factor was produced, fungi predominated (Newman and Barret, 1993).

Work done on different types of straw indicate that wheat, barley and linseed straw all produce the algal inhibiting factor but the best is barley straw (Newman and Barret, 1993).

The main effect of the algal inhibiting factor is that it inhibits only algal growth. Growth of *Cladophera glomerata* was inhibited in the presence of barley straw, but once removed and placed in water without straw and with adequate nutrients, growth returned to normal (Newman and Barret, 1993). The effect appears to be prevention of cell division rather than cell death, which therefore appears to favour those species that can survive without cell division.

Since the precise nature of the algal limiting factor has not been determined, the required concentrations are unknown. However, it has been shown in laboratory tests that 2.7 g/m^3 inhibited the growth of algae by 95 percent. In field trials, 2.4 bales / ha (each weighing 20 kg) have shown satisfactory results (Newman and Barret, 1993).

A number of barley straw tests have been carried out in the UK and Australia. These range from ponds and ditches to dams larger than 20 ha. Bearing in mind the dosage rate required, this technique may not be applicable to large impoundments.

In-lake Chemical Control of Phosphorus using Aluminium Sulphate

The addition of aluminium sulphate has become an alternative method of in-lake restoration, by reducing the internal loading of phosphorus. The principle involves the formation of a layer of aluminium hydroxide floc over the sediment. This is termed inactivation and is dependent on dosing the required concentration for removal of phosphorus from the water column (Welch *et al.*, 1982).

In Long Lake, Washington, large populations of blue-green algae were affecting the recreational potential of the lake. Extensive beds of rooted macrophytes (*Elodea densa*) were also present. These would die off in winter to about 20 % of the summer standing crop (Welch *et al.*, 1982). The high summer blooms of algae (and associated high concentrations of phosphates) were found to be attributable to internal loadings of phosphates from the sediments. It was decided therefore to treat the lake with 5.5 mg/ℓ of aluminium sulphate (Welch *et al.*, 1982). This was done in consecutive segments of the lake over an eleven-day period.

Initially, the level of the lake was lowered to consolidate the highly inorganic sediments and to reduce the macrophyte crop. Thereafter the lake was treated chemically.

It was found that the quality of the lake water improved significantly after these actions. Phosphorus concentrations were reduced from peaks of 0.1 mg/ℓ to 0.029 mg/ℓ. The decrease in phosphate was not only attributable to the action of aluminium sulphate removing phosphorus from the water column, but also due to the formation of a chemical barrier. Two years after application the concentrations were even lower (Welch *et al.*, 1982). This reduction in phosphorus in the water column also resulted in a decrease in algal biomass. Peaks of over 60 ug/ℓ were recorded prior to treatment but were reduced after treatment.

The persistence of the aluminium floc indicates that this technique may be applicable to shallow water bodies, such as urban impoundments. There are however, a number of aspects which affect the long-term suitability of this method, should it be used in isolation:

- The layer of aluminium floc persisted for at least two years. Data of its long-term suitability was unavailable, but work done on deeper stratified impoundments indicated an effectiveness for a period of five years (Cooke *et al.*, 1982).

- Macrophyte biomass increased because of the increased light penetration. Not only would this affect the use of the water for recreation, but macrophytes also act as a storage medium for nutrients, and therefore, once they die off, nutrients are released into the water.

The indications are, therefore, that should aluminium sulphate be pursued as a management option, then other strategies may have to be employed to harvest or reduce the resultant macrophyte biomass.

Cooke *et al.* (1982) identified the potential of aluminium sulphate application, but only after the diversion of phosphate-rich water. As previously discussed, the integration of a number of strategies may best solve water quality problems in urban impoundments.

2.3.3 Physical Control

Artificial Mixing / Aeration

Traditionally artificial mixing of impoundments has been undertaken to de-stratify the water column. In deep dams and lakes, the development of differing layers of water as a result of temperature and oxygen changes, causes the deeper layers to become anoxic. This results in chemical changes to the water, whereby increases in phosphorus concentrations can be seen. When climatic changes occur, the water between the oxygenated surface layer and the deeper anoxic layer becomes unstable and mixing occurs. This releases phosphates trapped in the lower layers, to the surface of the impoundment where it becomes available for algae.

If, however, the water column is mixed and there is no discernible stratification, the ratio of mixed depth to euphotic zone is greater. This results in a reduction in the average time spent in the euphotic zone by the phytoplankton, thereby reducing photosynthetic production and growth (Hawkins and Griffiths, 1993).

There are, however, more conflicting arguments on artificial mixing than other lake restoration techniques. The arguments are as follows.

Pro-mixing

Hawkins and Griffiths (1993) found that in a small impoundment in Australia, the phytoplankton present prior to any form of artificial mixing predominantly comprised blue-green algae (including *Anabaena* sp.). Additionally the in-lake chlorophyll *a* concentration peaked at over 90 ug/ℓ. After mixing, the algal populations were dominated by diatoms which were again superseded by blue-green algae once the silica content of the water was depleted. The result of the emergence of the diatoms was a decrease in chlorophyll *a* to half that prior to mixing. Additionally, hierarchical fusion analysis, based on the biomass species, differentiated the phytoplankton samples into cluster groups that could be related primarily to stratification or mixing of the water column (Hawkins and Griffiths, 1993).

Anti-mixing

Results of an artificial mixing experiment undertaken by Osgood and Stiegler (1990) showed that internal phosphorus loading increased after the onset of artificial mixing. The increase nearly tripled the water concentration of phosphate, from 0.152 mg/ℓ to 0.305 mg/ℓ. This resulted in a doubling of the algal concentration at the surface. Additionally, the transparency of the water decreased from 0.7 m (secchi disk reading) to 0.3 m.

The impact of motor boats on the water quality of a lake has also been investigated. Although not considered as a traditional mixing method, it can still have an influence on the circulation of phosphorus within an impoundment (Yousef *et al.*, 1980). Results indicated that there was a significant increase in turbidity and phosphate concentrations, as a result of the mixing. An increase in phosphate up to 0.1 mg/ℓ was observed and suspended sediment (as turbidity) increased from 0.02 JTU to 0.08 JTU after mixing.

It appears, therefore, that the application of this technique requires caution. The benefits derived from increased aeration and mixing on algal speciation must be considered against the potential for an increase in phosphorus in the water with the concomitant increase in algal population.

Dredging to Remove Sediments

As a result of the accumulation of sediments in dams and lakes due to inflowing sediment settlement, a number of processes occur:

- the impoundment silts up, reducing the depth of the water, which affects recreation, fish populations and the potential for dense stands of macrophytes to develop;
- the sediments act as sources of nutrients for algal growth; and
- the sediment may accumulate toxic substances which affects water quality.

The removal of sediment from the dam to deepen it has been practised for a number of years all over the world (Peterson, 1982). Although successful, this technique is usually required frequently, because the source of the sediment is normally not considered. An integrated system of catchment management is needed to reduce the sediment load so that the benefits derived from sediment removal can be seen for a longer period of time (Peterson, 1982).

In shallow lakes the release of sedimentary phosphorus may be significant in creating more favourable conditions for algal growth (Peterson, 1982). Phosphates may be derived from two sources :

- chemically bound to the inflowing sediment itself which settles out in the lake; and
- bound in the biological populations which, on death, settle to the bottom of the lake (Grobler and Davies, 1979).

The chemical structure bonding phosphate with the sediment can be expected to vary, depending on the source of the sediment and its geology (Grobler and Davies, 1979). Most phosphorus release occurs under anoxic conditions, but will also occur under aerobic conditions although at a slower rate. In addition, it appears that acidic and alkaline sediments exhibit accelerated phosphate release. Bacterial activity also appears to play a significant role in the release of phosphate from sediments (Grobler and Davies, 1979). This activity would assist in the decomposition of dead organisms and the subsequent release of the nutrients to the water column.

The reintroduction of phosphate into the water column from the sediments can occur via a number of mechanisms:

- wind mixing;
- metabolic activity;
- inflow of rivers;
- tides; and
- human activities, such as boating (Grobler and Davies, 1979).

These activities cause the phosphate to be mixed in the euphotic zone, where it is available for algal production.

In some instances it is therefore beneficial to remove the sediment, which has a high concentration of phosphorus, in order to reduce this internal loading, especially if the impoundment has been subjected to high external loadings of nutrients and the sediments have become saturated (Grobler and Davies, 1979).

In Lake Trummen, an external source of nutrients was removed in 1958 but no improvement in the lake's trophic status occurred (Cronberg, 1982). In 1970 and 1971, approximately 0.5 m of FeS-enriched sediment was removed through suction dredging. The sediment was deposited in settling ponds beside the lake. Runoff from the sediments was treated with aluminium sulphate to reduce phosphorus concentrations before it was returned to the lake.

This lake restoration project lead to large changes in the phytoplankton populations (Cronberg, 1982). The dredging operation removed 50 Mg of phosphorus and 450 Mg of nitrogen from the lake system. At the same time cysts, spores, auxospores, zygotes, resting cells of algae and other organisms were removed. The net result was mainly the removal of the blue-green algal population.

The restoration of Lake Trummen induced an immediate and drastic reduction in phytoplankton biomass and species diversity increased (Cronberg, 1982). The cost of dredging impoundments is influenced primarily by the size of the impoundment and the distance from a suitable disposal site for the sediment. It appears that dredging impoundments where high sediment phosphorous concentrations are found is viable, but it should not be viewed in isolation and rather as one method which can be employed in lake restoration.

Macrophyte Control

The Botanical Research Institute of South Africa compiled a number of fact sheets regarding aquatic weeds in 1980. At present these fact sheets are undergoing a revision. These sheets provide photographs of the plants, some botanical information, their ecology, distribution, and their importance.

Chemical Control of Macrophytes

The use of herbicides on particular aquatic plants is controlled by legislation and only those herbicides registered are allowed to be used. Direct chemical control of aquatic weeds has achieved limited success in the past (Hartbeespoort Dam and Bon Accord Dam). Glyphosate herbicides have been successful on water hyacinth, kariba weed, water lettuce and waterlilies. Terbutryn herbicides were used to control hyacinth at Hartbeespoort Dam. The effectiveness of chemical control is dependent on a number of factors:

- The spray technique must follow the manufacturers recommendations exactly. Droplet size is important as well as the angle of the boom (Marshall, 1991). The larger the droplet size, the less the likelihood of drift occurring. In aerial spraying, the angle of the boom is important as the forces acting on the droplets can cause shattering and thus fine droplets are formed (more prone to drift). Surfactants such as “Get Down”, are used to reduce shattering and to increase the adhesion of the herbicide onto the plant.
- Small areas are difficult to spray by aerial means, therefore backpack spraying is used. This is labour-intensive and the effectiveness is dependent on the expertise of the labour force.
- Adequate cover of the foliage must be accomplished. Systemic herbicides need complete cover for them to be totally effective. “Burn-down” type herbicides can do a lot of damage if not completely saturated, but their effect is also reduced and the plant may regrow.
- Follow up spraying is required to maximise the effect of the spraying programme.
- The timing of the spraying must coincide with the growth phase of the plant. It is not effective to spray if the plant degenerates or even dies during winter. Often spraying will coincide with the abstraction of water for irrigation, therefore the choice of herbicide is important and must be site-specific.

The effectiveness of some herbicides can be improved by using floating materials as herbicide carriers.

From a cost point of view, herbicides range between R180 to R400 per hectare (1996) and the cost of the equipment must also be included. This means that herbicides are high cost controls, but can range from slow to quick response depending on the type. Systemic herbicides take approximately 1 to 2 months to take effect, while burn-down type herbicides are faster acting, normally needing 1 month to affect the plant.

A number of chemicals are available for aquatic weed control:

- *Glyphosate*. Chemical compound: N- (phosphonomethyl) glycine. This compound is also known as “Roundup”. It is a systemic herbicide that is absorbed through the leaves and stems of plants, which inhibits the production of aromatic amino acids, essential for plant growth and development. (Marshall, 1991). It is used primarily on broad-leaved plants. It is registered for use on : water hyacinth, water lilies, common reed and red water fern.
- *Terbutryn*. Chemical compound: 2- tert-butylamino-4-ethylamino-6-methylthio-s-triazine. This compound is also known as “Carosan”. It is a systemic herbicide but also has a burn-down effect. This scorches the leaves as well as inhibiting amino acid production. It is primarily used on broad-leaved plants and is registered for use on water hyacinth.
- *Diquat*. Chemical compound: 6,7-dihydrodipyrido pyrazinediinium ion. This compound is marketed as “Weedmaster Aquacide”. It relies primarily on its burn-down property to destroy the plant. It is registered for use on water hyacinth and kariba weed.

- *Proprop*. Chemical compound: unknown. This product is marketed under a variety of names as it is a saleable compound. It has some systemic properties but also some burn-down properties. It is an industrial herbicide for use primarily on grass types and is registered for use on reeds and bulrushes.
- *Amitrole*. Chemical compound: 3-amino-s-triazole. This product is marketed as “Weedmaster Weedazol”. Its action is similar to that of *Proprop* and it is registered for the same plants.
- *Glufosinate-ammonium*. Chemical structure : not yet released. This product is marketed as “Buster”. It is in the process of being registered for water hyacinth. It is a partial systemic, partial burn-down herbicide.
- *Growth retardants*. This is an area which has shown promise in the past but the specific information regarding the type of compound still needs to be determined. A number of potential products are available such as “Velpar” and “Maintain CF-125”.
- *Copper sulphate*. This compound has been used for controlling the growth of *Cladophora* sp. in canals.

The indirect chemical control of plants is difficult to assess. The reliance of aquatic plants on nutrient-rich water gives no indication of the concentration at which the element becomes limiting. As an ultimate solution, however, the reduction in nutrients should reduce the level of aquatic plants as well as improve the quality of the water. This measure should be seen as a “last resort” control strategy. The cost of complying with the 1 mg/ℓ Special Phosphate Standard is high, although the benefit is the overall improvement in water quality for all water users.

Another method of control which could be utilised is the manipulation of the ionic structure of the water (Springell and Blake, 1975). More work needs to be done, however, on the effectiveness of this strategy.

Biological Control

The biological control of aquatic plants has received growing attention because it offers the opportunity for a one-time application and is a natural remedy. The control of Kariba weed and water lettuce is already far advanced. (Bruwer, 1991; Reid, 1991; Davidson, 1991). The bio-control of water hyacinth has shown great promise and has achieved success in certain areas for a number of years.

The effectiveness of the biological control is dependent on a number of factors:

- The agent must be a natural control and be host-specific. Forcing biological agents to control certain plants in a laboratory by starving them, is no guarantee that the process will be effective at full-scale.
- The climate may play a very important role as insects are cold blooded animals and therefore environmental tolerances are important factors in achieving maximum control. It has been hypothesised that the control of hyacinth in certain areas is not effective because of this fact (Reid, 1991).
- The control agent must be self regulating. In South Africa, host specificity is the governing factor regarding selection of a bio-control agent, and thus its growth will be linked to the size of the host population.
- The effect of pathogens such as viruses, bacteria and fungi, needs strict control by specialist scientists and must be carefully monitored after release. An effective control strategy in one part of the world is no guarantee of success in South Africa. The allelopathic control of certain aquatic plants needs more investigation (Pearce, 1987).

The use of bio-control agents is seen as a long-term, optimum control of aquatic plants. The control of plants in this manner will not totally eradicate the problem but will allow the populations to be reduced to below their nuisance level. It is expected that the populations of host and control will stabilise into the classic predator - prey cyclical relationship.

The relative cost of these controls is low and the research and development costs are also fairly low. It must be emphasised that bio-control is not a fast control strategy. In South Africa, it has taken five years for the first agent released to reach the stage where it has started suppressing water hyacinth.

Biological control mechanisms include:

- *Eichhornia*. A number of bio-control agents have been found for the control of hyacinth. The weevil *Neochetina eichhorniae* has been extensively used (Cilliers, 1991; Bennett, 1976; Cassani *et al.*, 1981) and effectively reduces plant growth rate and fecundity. Other potential agents under investigation are:
  - a beetle : *Neochetina bruchi*
  - a mite : *Orthogalumna terebrantis*
  - a moth : *Sameodes albiguttalis*
  - fungi/pathogens: *Cercospora rodmanii, c. Piaropi and Alternaria eichhorniae.*
  - Future studies will include : *Bipolaris* sp*. Fusarium* sp*. Rhizoctonia* sp*. Uredo* sp. (Charudattan *et al*., 1974; Cilliers, 1991)
  - the existence of allelopathy by water hyacinth has not been conclusively proved either way (Seaman and Porterfield, 1964; Pearce, 1987).
- *Salvinia*. The Kariba weed is at present being controlled by *Crytobagous salvinae* (Nel, 1991). This weevil damages the plant by feeding on the growth tips and burrowing into the rhizome, thus causing the plant to die prematurely.
- *Pistia*. The water lettuce is at present being controlled by *Neohydronomous affinis*. This weevil's feeding activity causes larval mining and eventual plant collapse.
- *Myriophyllum*. The control of *Myriophyllum* by biological agents is still at an early stage. The types of control being investigated internationally include:
  - a weevil: *Pelenomus impressiventris Blatchley*
  - a moth: *Paraponyx stratiotata*

  - grass carp: *Ctenopharyngodon idella*
  - a plant: *Eleocharis acicularis* (Pieterse, 1977; Robson, 1977).
- *Azolla*. Information on the biological control of *Azolla filiculoides* is limited. An agent that could be used is a small flea beetle, *Pseudolampsis guttata Leconte.*

Mechanical Control

The effectiveness of mechanical control is usually restricted to small areas. Where large dense growth occurs, the re-growth is often faster than the removal rate (Reid, 1991). Additionally the problem of disposal occurs. With chemical and biological control the plants are absorbed into the natural aquatic environment, but with mechanical removal the plants are translocated onto land.

The control method involves the symptomatic removal of plants. In the Vaal River, control of hyacinth occurs from a point 50 kilometres upstream of the Bloemhof Dam. Liebenberg (1991) has identified that plants are transported downstream in the Vaal River from the Vaal River Barrage when water releases are made. A control strategy for the whole river should improve the effectiveness of mechanical control without drastically increasing the costs.

The costs of mechanical removal are high. The design, construction and maintenance of machines are costly, labour costs are ever-increasing, and the maintenance of barriers and fences is expensive. The cost of natural shading is initially high but becomes negligible once the costs of the canopy have been depreciated.

Mechanical control of aquatic weeds is done by both active and passive methods:

- In terms of active control, mechanical harvesters have been developed primarily for the control of water hyacinth. In certain areas they may be used as an alternative to chemical and biological control but removal and disposal costs are high (Cifuentes and Bagnall, 1976). Harvesters generally have a mechanism to concentrate the plants, a conveyor for collection and either a dumping area or a crushing machine (Phillippy and Perryman, 1972; Bureau of Aquatic Plant Research and Control, 1972).

  Simple cutting systems have been developed for submerged and emergent plants (Mcveigh, 1980).

  Booms, nets, rakes and other barriers are used to either prevent aquatic weeds from encroaching into an area or for concentrating the plants where they can either be sprayed or manually removed.

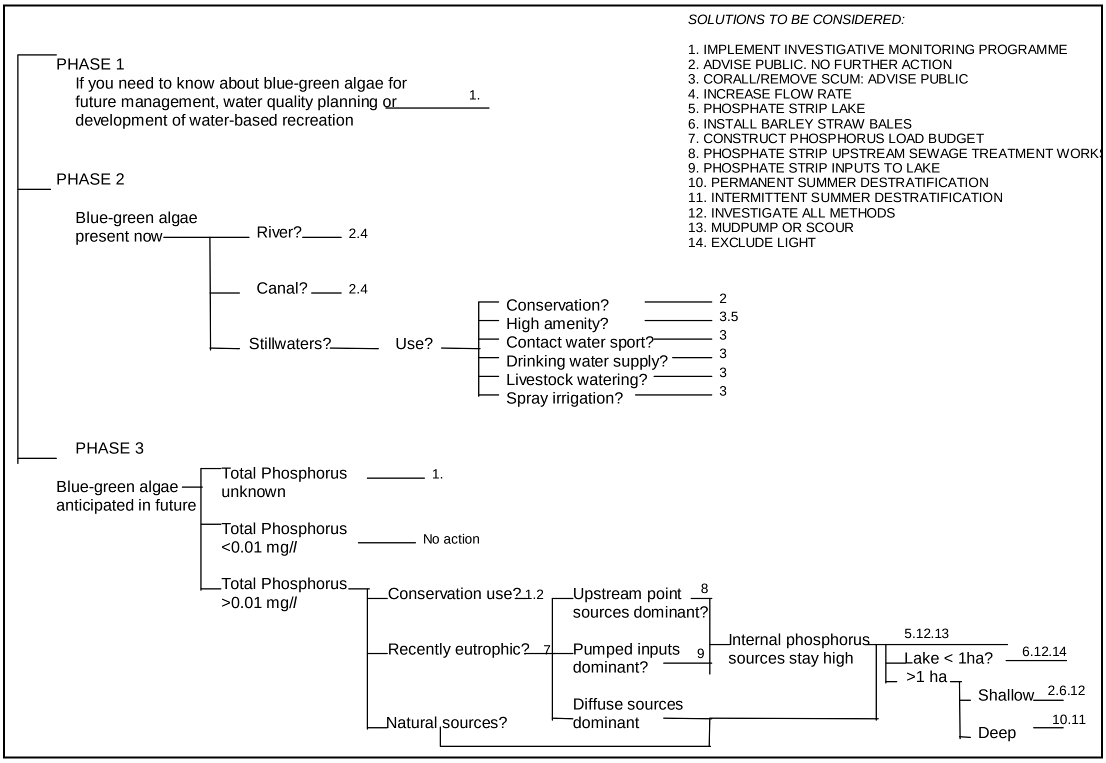
  Manual removal involves labourers hooking the plants with long poles and removing them to the banks of the impoundment or river.

- Passive control is effected mainly by shading, thus reducing light penetration. The shading system can either be artificial (man-made), such as benthicemi-barriers laid directly over the growing plants (Mayer, 1977) or shade cloth over small impoundments and canals (Bruwer, 1991) or natural (vegetation). Natural shading is achieved by enhancing riparian vegetation, the planting of reeds or the use of floating aquatic plants (Dawson and Kern-Hansen, 1978; Dawson Kern-Hansen, 1979; Jorga *et al*., 1982).

3. CONCLUSIONS

The management options described in this document outline the available techniques which may be deployed in any urban impoundment management strategy. The choice of strategy will depend on a number of factors. The ultimate aim of this research project is the development of certain guidelines which will enable urban impoundment managers to identify a water quality problem, to choose a strategy, and to monitor the effect of the chosen strategy. An example of such a decision tree, presented in Figure 3, focuses on the options available for managing blue-green algae. This tree was developed by the National Rivers Authority (1994) in the United Kingdom.

Figure 3 : Decision Support Tree for Blue-green Algae



The optimum management of urban impoundments will likely comprise a combination of catchment management, pre-impoundment management and in-lake treatment techniques. The most effective strategy will include a combination of the three groups of techniques and will take into account the local conditions prevalent in a specific region.

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