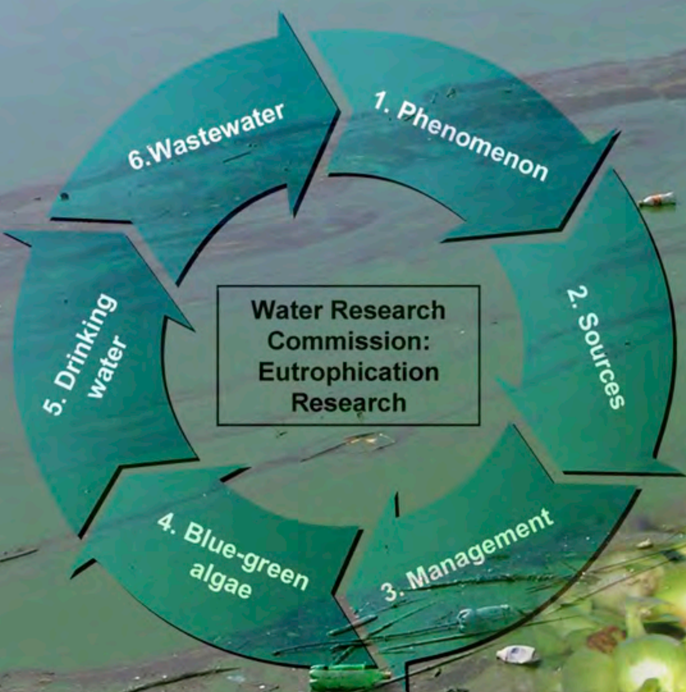
# Eutrophication Research Impact Assessment

Frost & Sullivan




WATER RESEARCH COMMISSION

TT 461/10

# Eutrophication Research Impact Assessment

Report to the

**Water Research Commission**

by

**Frost & Sullivan**

**WRC Report No. TT 461/10**

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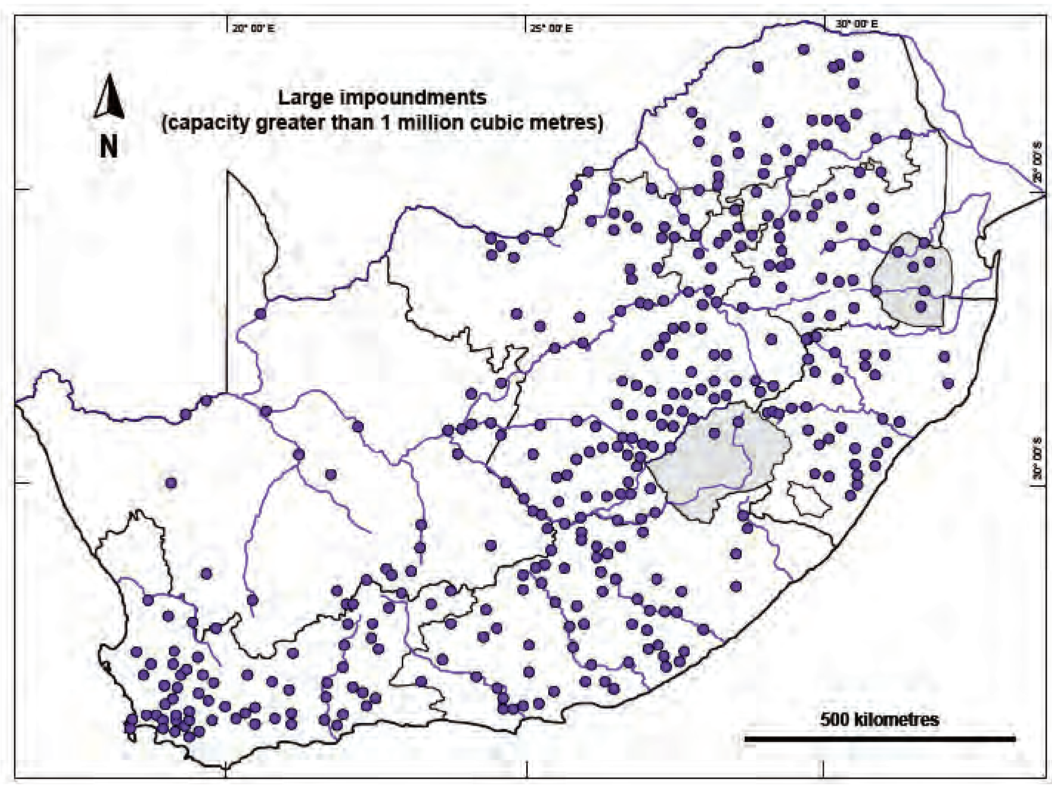
# 1. Introduction

Eutrophication is a phenomenon that has adverse and often dangerous effects on freshwater systems all over the world, when caused by the effects of human activity (anthropogenic eutrophication). A body of water, such as a lake or dam, is deemed eutrophic when it undergoes high primary production of organic compounds due to an overload of nutrients. This over-production of compounds results in algal blooms which may have negative implications for water quality. Amongst other impacts, eutrophication may lead to oxygen deficiencies in the system, a lack of fish and other aquatic life and health implications for water users. South Africa has some of the most enriched surface water in the world and thus eutrophication presents a major problem. The map below depicts the distribution of large water impoundments in South Africa.

***Figure 1: Distribution of Large Impoundments in South Africa***




The following table provides an indication of the extent and severity of eutrophication, as recorded by DWAF in 2008.

*Table 1: Sample of the Extent and Severity of Eutrophication in South Africa (DWEA)*

| Dam | Level of Severity |
|---|---|
| | |
| Hartbeespoort Dam | Serious |
| Roodeplaat Dam | Serious |
| Klipvoor Dam | Serious |
| Rietvlei Dam | Serious |
| Boskop Dam | Serious |
| Loskop Dam | Significant |
| Spitskop Dam | Serious |
| Krugersdrift Dam | Serious |
| EJ Smith Dam | Serious |
| Shongweni Dam | Serious |
| Laing Dam | Serious |
| Bridledrift Dam | Serious |
| Nahoon Dam | Significant |
| Theewaterskloof Dam | Significant |
| Voelvlei Dam | Significant |

The Water Research Commission (hereafter referred to as WRC) has been extensively involved in eutrophication research since its inception. The organisation is a statutory institution established in 1971 by an Act of parliament. The WRC represents a dynamic hub for water-centered knowledge, innovation and intellectual capital. It provides leadership for water-related research and development through the support of knowledge creation, transfer and application. To date the WRC has published approximately 84 research studies that focus on eutrophication, its treatment and its management.

In an effort to retain and strengthen its position as a “value for money” institution delivering research and innovations that contribute to socio-cultural, economic, political, technical and environmental aspects in South Africa, the WRC has embarked upon a number of studies to assess and portray the impact of its research programmes and resulting products and their benefits to the country.

The WRC has limited capacity to conduct such evaluations hence it has commissioned international growth consulting company Frost & Sullivan to support on a review of selected research products and/or programs, one of which is within the area of eutrophication related research.

## 1.1 Project Aim and Objectives

**Project Aim**

**The aim of this project is to provide the WRC and its stakeholders with a concise assessment of the impact (to date and future potential impact) of the WRC *Eutrophication* investments and products on socio-cultural, economic, political, technical and environmental aspects of South African society.**

**Project Objectives**

- **To map the full extent of domestic water quality research funded and published by the WRC since 1984.**
- **To outline the application (to date and expected future application) of the research and products in South Africa (and internationally if relevant).**
- **To determine the impact of the research and products (as per the project aim above).**
- **To relate the outcomes / impact of the developed products to a common measure such as "Rand value of research product impact".**

## 1.2 Project Scope

This section outlines the geographic and technical scope of this project.

### Geographic Scope

This project considers the impact of WRC research projects in all regions within South Africa. However, where international applications of WRC research and sales of funded products were apparent, these were also incorporated in the analysis.

Please note that research on eutrophication nationally and during this study period 1984-2009 was not confined only to WRC. Other research was conducted as well but for the purposes of this study, focus is made only on WRC research.

### Technical Scope

This project considers and evaluates all research projects and products developed and published by the WRC since 1984 which relate to eutrophication.

## 1.3 Consulting Approach and Methodology

For consulting projects, Frost & Sullivan utilises tried and tested marketing techniques to provide structure to the research and its results, which allows the effective analysis, review and comparison against industry benchmarks.

This project was carried out using primary research (telephone or face-to-face interviews) and secondary (published and online material) research as the principle methods of data gathering.

Frost & Sullivan interacted with the following respondent groups and stakeholders:

| Organisation Type | Target Designations | Type of Information |
|---|---|---|
| **Water Research Commission** | Project Managers, Research Managers, Programme leaders | Research projects conducted<br>Products developed<br>Application of products |
| **Research Institutes (Universities / Consultants)** | Project Leaders, Researchers and Lecturers | Water research provided<br>Water related products developed |
| **Government Departments** | Policy Directors, Environmental Health Directors | Alignment of WRC projects and policy development<br>Impact of research on water management |
| **NGOs** | Programme Managers, Environmental Activists | Awareness of WRC research<br>Importance of WRC research to national and local water management |
| **Associations / Other** | Industry Specialists, Consultants, Associations | Perceived impact of WRC products<br>Supporting information to substantiate findings |

## 1.4 Overview of WRC

The WRC is a statutory organisation established in 1971 by an Act of Parliament. The organisation represents a dynamic hub for water-centered knowledge, innovation and intellectual capital. The WRC provides leadership for water-related research and development through the support of knowledge creation, transfer and application. The WRC engages stakeholders and partners in solving a wide variety of water related problems, which are critical to South Africa's sustainable development and economic growth.

Funding its projects through levies on national water sales, the WRC faces many challenges including: the creation of appropriate and relevant new water-centred knowledge, the dissemination and application of research, network creation and knowledge building capacity.

## 1.5 Definitions

**Cyanobacteria:** Cyanobacteria (blue-green algae or blue-green bacteria), is a phylum of procaryote bacteria that obtain their energy through photosynthesis. They are a significant component of the marine nitrogen cycle and an important primary producer in many areas of the ocean, but are also found to occur in freshwater systems.

**Diatoms:** Microscopic unicellular marine or freshwater colonial alga having cell walls impregnated with silica

**Eutrophication:** An increase in the concentration of chemical nutrients in an aquatic ecosystem to an extent that increases in the primary productivity occur. Negative environmental effects, such as anoxia and severe reductions in water quality, fish, and other animal populations may occur as a result.

**Phosphate:** A chemical plant nutrient, the concentration of which is most often found to limit the level of algal growth in water bodies. Phosphorus management forms the backbone of eutrophication attenuation approaches.

**Phytoplankton:** A floating layer of photosynthetic organisms, including algae, that are an important source of atmospheric oxygen and form the base of the aquatic food chain.

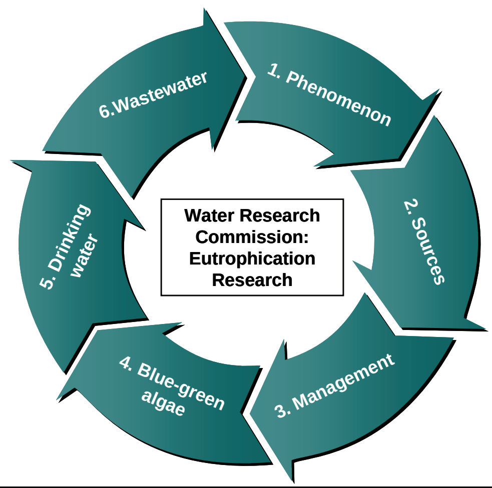
## 1.6 Overview of the WRC's Research on Eutrophication

Research conducted by the WRC into water resource management and water-linked ecosystems, specifically in the field of eutrophication, addresses the conservation of aquatic ecosystems with the aim of providing knowledge as to their sustainable functioning. This supports national commitments to global standards and recognition of the ongoing provision of goods and services delivered by these natural systems.

Furthermore, this specific area of strategic research focuses on the protection and sustainable utilisation of the aquatic environment. This supports and provides knowledge to the National Water Resource Strategy (NWRS), which focuses on resource protection as a key component.

Figure 1 below provides a focus overview of the six categories of eutrophication-related research conducted by the WRC.

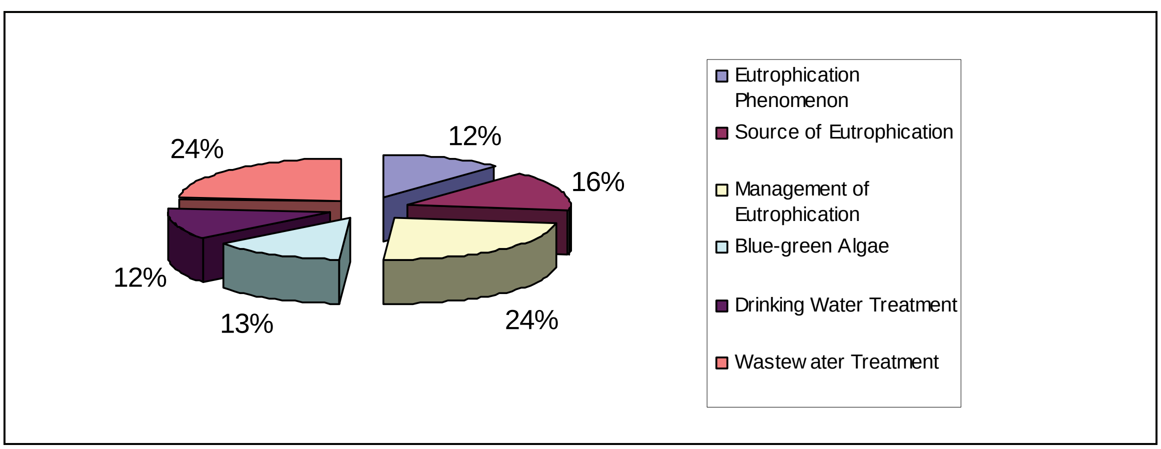
***Figure 2: Research categories***




**Category 1:** The eutrophication phenomenon
**Category 2:** The sources of eutrophication
**Category 3:** The management of eutrophication
**Category 4:** Blue-green algae
**Category 5:** Drinking water treatment adaptations
**Category 6:** Development in wastewater treatment to remove phosphorus

Figure 3 below indicates the research focus split across the categories, over the period from 1984 to 2009.

***Figure 3: Research focus***



The research focus is almost equally spread between most of the categories, with no one category receiving a disproprotionate amount of attention.

Figure 4 below provides an overview of the timing of the reports that were produced by the WRC between 1984 and 2009, giving an indication of how the research focus shifted from understanding the scope and causes of eutrophication towards its management and treatment.

***Figure 4: Publication of reports between 1984 and 2009***

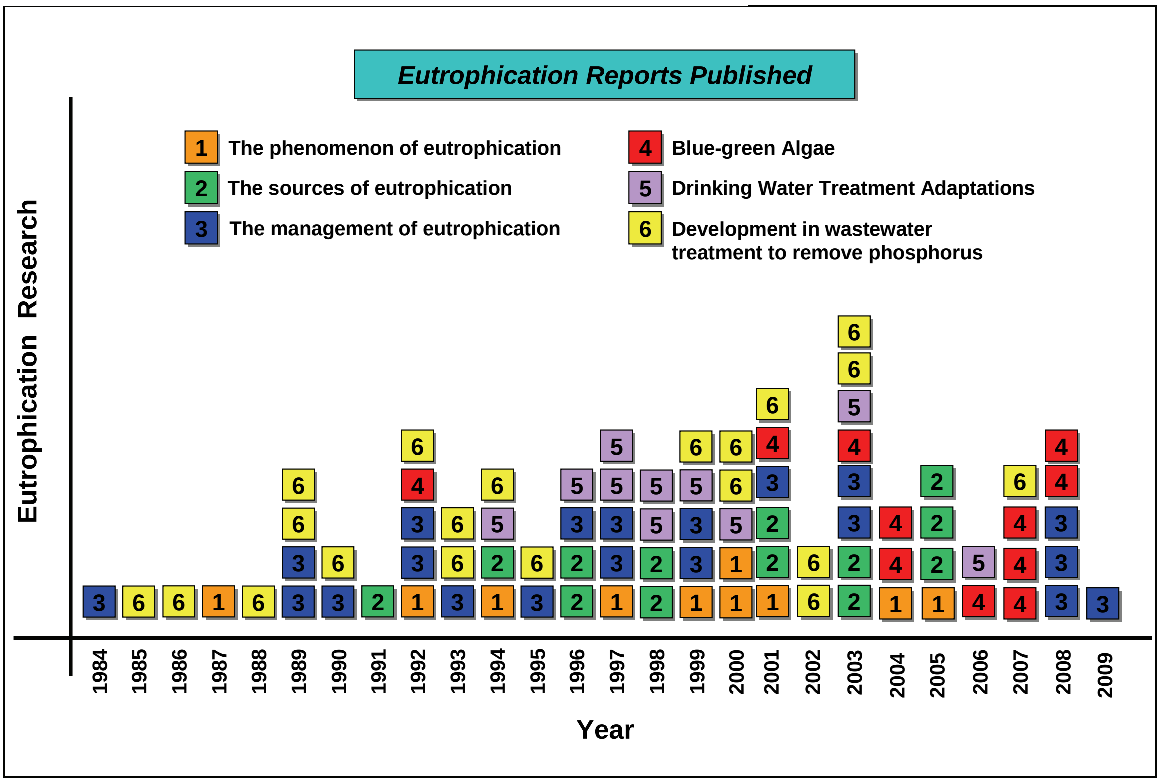
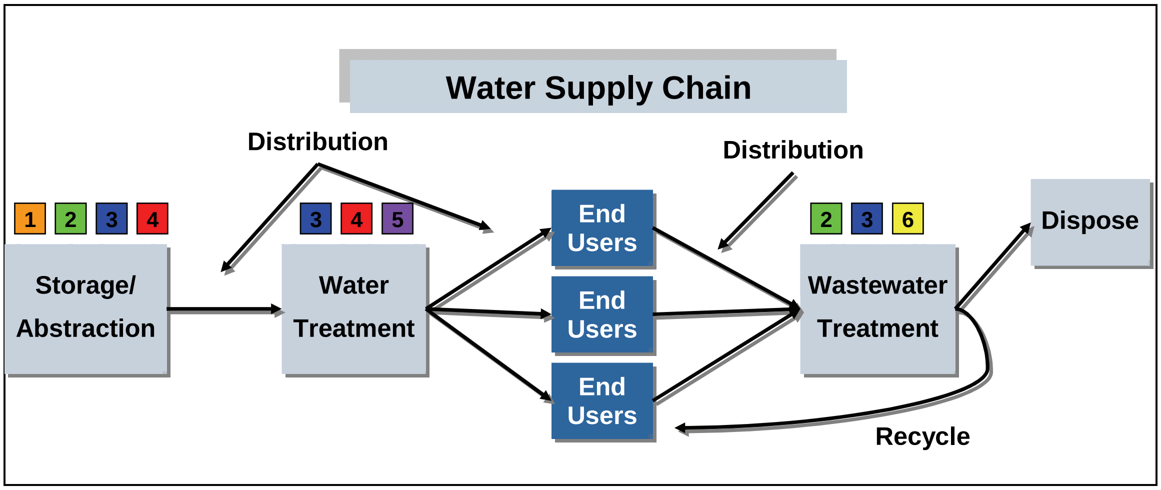



Figure 5 below maps the eutrophication research categories against the water supply cycle, indicating those stages of the water supply cycle where the research has a direct impact or focus.

*Figure 5: WRC research and the Water Supply Chain*




**Detailed overview of categories**

***Category 1: The phenomenon of eutrophication***

The research in this category addresses the underlying process which leads to eutrophication arising in an acquatic ecosystem. Emphasis is placed on identifying what eutrophication is and the reasons for its incidence. Certain studies also analyse policies and research related to the phenomenon in South Africa.

***Category 2: The sources of eutrophication***

Research in this category addresses the causes of eutrophication in detail. Known and/or potential anthropogenic causes of the phenomenon are analysed in depth, through site studies and simulations, in order to provide details regarding each factor's level of impact in causing a system to become eutrophic.

***Category 3: The management of eutrophication***

With the reasoning behind and causes of eutrophication identified, the research in this category addresses control models and measures for managing the problem across various freshwater systems. The research also analyses new and/or innovative management measures and assesses their viability in a South African and global context.

***Category 4: Blue-green algae***

Given that blue-green algae are potentially a toxic and dangerous consequence of eutrophication, and is indeed a strong indicator thereof, the research in this category studies this algae in detail. Emphasis is given to monitoring the nature, causes and effects of blue-green algae, as well as means for its detection and management.

***Category 5: Drinking water treatment adaptations***

The research in this category analyses the consequences of eutrophication for potable/drinking water and how best to adapt the treatment of water made available for personal consumption to filter algae and remove toxins, tastes and odours. Various treatment options are detailed for treatment plants of all sizes. Measures for assessing the levels of toxins in water earmarked for this use are also identified and discussed.

***Category 6: Development in wastewater treatment to remove phosphorus***

Biological effluent from sewage plants, released into freshwater systems, is one of the main causes of eutrophication as it contains very high levels of phosphates. Studies in this category address the removal of these phosphates as a proactive approach to managing eutrophication, which in turn reduces the pressure to symptomatically manage and heal a system already affected by the problem.

## 2. Background to Eutrophication Research

The WRC has been conducting research related to eutrophication since soon after its inception. Early research focused predominantly on the management of eutrophication and the development of wastewater treatment methods to remove phosphorus, one of the main causes of eutrophication in receiving water systems.

The WRC recognised the problem of eutrophication soon after it was founded in 1971. Project No 8 was for example entitled “Eutrophication of rivers and dams”, while Project No 22 investigated the biological denitrification and the removal of phosphate from sewage. These projects dealt primarily with a study of the eutrophication phenomenon and the development of wastewater treatment technology to remove Phosphorus, but they also provided early guidance for the management of eutrophication. These early projects thus culminated in reports which provided initial guidance concerning issues that are still of concern today (see Appendix for full list of reports). These and other early research projects were reported on in research papers and publications of the institutions conducting the research. It is only since 1984 that the WRC started with its own report series. The rest of this report will deal only with WRC reports published since 1984.

As of 1991, studies exploring the sources of eutrophication began to emerge. These gradually increased in frequency from 1996 to 2009.

Between 1994 and 2000, a number of studies addressed the adaptations of drinking water sourced from eutrophic water bodies, exploring means to filter algae and remove toxins, odours and tastes from the water. These studies were conducted on an annual basis between 1996 and 2000.

Research analyzing the phenomenon of eutrophication began in 1992 and was conducted infrequently until 2005.

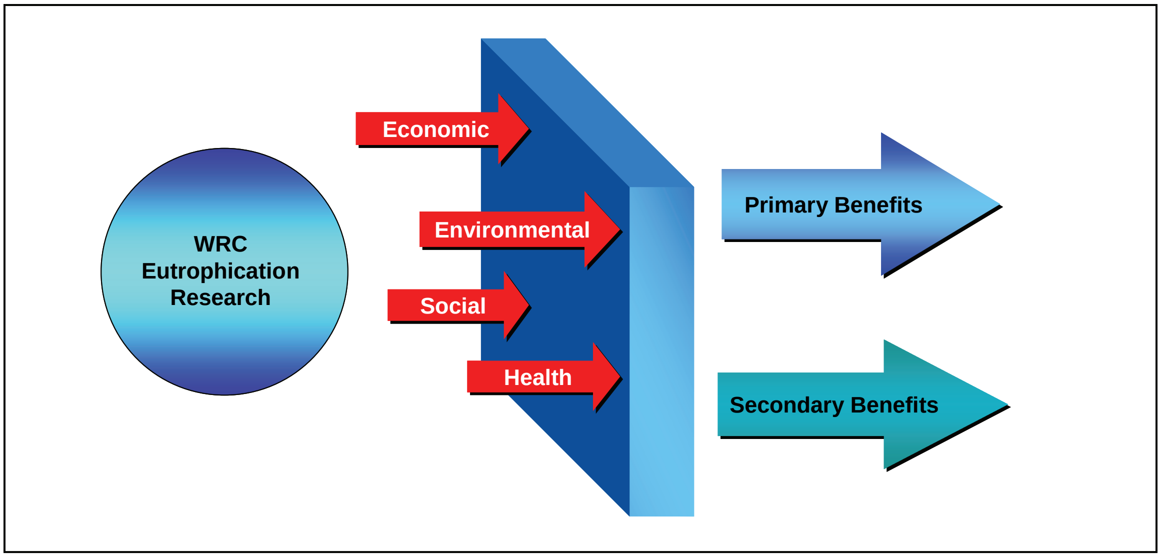
The majority of all research was conducted between 1996 and 2008. The latter half of this period saw a marked increase in studies of cyanobacteria (blue-green algae), one of the dangerous consequences of eutrophication.

## 3. Impact of Eutrophication Related Research in South Africa

**Overview**

The Water Research Commission has conducted eutrophication research in South Africa across a broad range of categories. The conclusions and related applications of this research impact various economic, environmental, social and health considerations. A combination of primary and secondary benefits to society may be derived from these impacts. Primary benefits are directly attributable to WRC research findings, whilst secondary benefits are an indirect result of WRC research into eutrophication.

*Figure 6: Overview of Impact Assessment*




## 3.1 Assumptions

Assessing impact, particularly related to research, can be a challenging process as impacts may often be intangible or too complex to quantify. In light of this, this project has aimed to utilise a common, quantifiable measure across the impact areas identified. This impact assessment has aimed to attach a Rand value to each impact identified. In many cases this is very difficult or not possible. Often, the most effective approach is to assess the potential cost saving attached to the implementation of the WRC research findings. It is beyond the scope of this assessment to consider all impacts attributable to WRC research. Rather, examples of major impacts are quantified to provide a comprehensive sample.

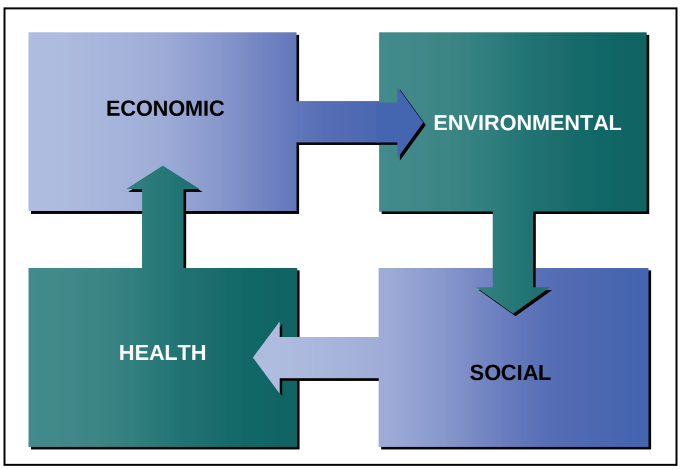
## 3.2 Impacts

The impacts analysed in this assessment are closely interlinked.

The **economic** impacts analysed in the document refer to aspects such as revenue generation and prevention costs. The **environmental** impacts examined refer to the far-reaching impacts that eutrophication may have on the immediate and greater environment. The **social** impacts consider the effects of WRC eutrophication research on society as a whole. Finally, the **health** impacts highlight the effect that eutrophication may have on the wellbeing of individuals who come into contact with eutrophic water.

In this study, Frost & Sullivan's focus was as outlined above. The WRC prides itself in its quest for scientific excellence. It would thus also be advantageous to assess the scientific impact its eutrophication related research has had. This could be obtained through a number of means, such as calculating the number of publications emanating from WRC research projects, their citation factors and the degree to which WRC research has contributed to the creation and support of tertiary centres of excellence. This approach would highlight innovative findings and international recognition attributable to WRC research. This process represents an alternative approach to assess the impact of research and may be the subject of a future investigation.

***Figure 7: WRC Eutrophication Impacts***



## 3.3 Economic Impacts

### 3.3.1 Introduction

The phenomenon of eutrophication has significant economic impacts, as it presents a critical problem that affects both human and animal life, and requires urgent treatment and prevention. Research funded by the WRC has explored these impacts, highlighting the negative effects of eutrophication from an economic perspective and detailing treatment and prevention methods. A sample of such research is provided below.

***Table 2: Examples of WRC Eutrophication Research with Economic Impact***

| Report | Study |
|---|---|
| 558/1/96 | Algal rupture during abstraction from reservoirs and the consequences for water treatment |
| 443/1/97 | Guidelines for the use of peroxone and other oxidants for the treatment of eutrophic and coloured waters in South Africa |
| 615/1/98 | Modelling the water quality in impoundments within the Umgeni Water operational area and the consequences for potable water treatment costs |
| 137/1/86 | The enhancement of biological phosphate removal by altering feed process composition |
| 314/1/93 | Research on biological phosphate removal in activated sludge |
| 289/1/92 | The management of phosphate concentrations and algae in the Hartbeespoort Dam |

In particular, this research has focused on cost-savings, wherein early warning systems and nutrient standards, suggested and tested in the research, have been implemented.

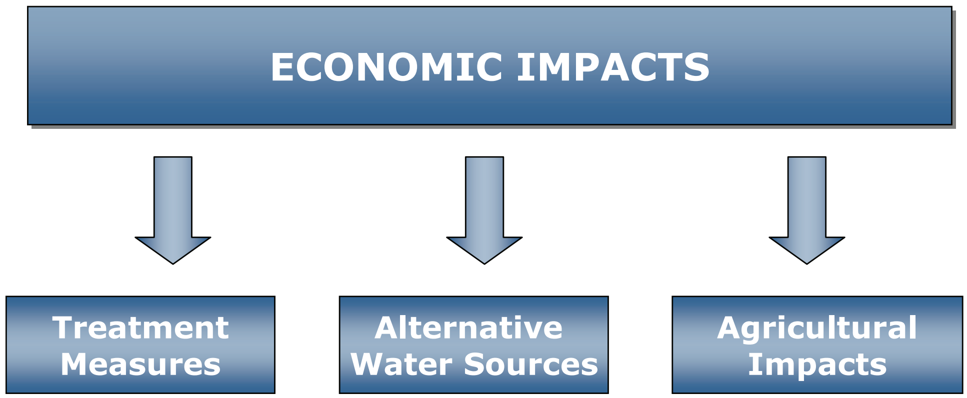
**COST OF EUTROPHICATION GLOBALLY**

Eutrophication is not a South African specific problem. Water managers across the globe battle with the direct and knock-on effects of eutrophic water.

A study conducted in England (Pretty, Mason, Nedwell, Hine, Leaf & Dils, 2003) calculated that the damage costs of freshwater eutrophication for England and Wales are £114 million (ZAR 1.2 billion), with associated treatment costs of £54 million (ZAR 581 million) per annum.

Some of the economic impacts of WRC eutrophication research may be broadly categorised across treatment measures, alternative water sources and agricultural impacts.

*Figure 8: Overview of Economic Impacts*




### 3.3.2 Quantification of Impacts

**TREATMENT MEASURES**

**Introduction**

All surface waters have the potential to carry pathogenic micro-organisms and are required to be disinfected before human consumption occurs. Various chemicals are added to address colour, tastes, odours and pH levels. Raw potable water, sourced from a water body subject to eutrophication, is treated at a water treatment works (WTW) by two common processes in South Africa, namely using ozone or using powdered activated carbon (PAC). Both treatment methods depend on the scope, nature and extent of eutrophication at a particular site and may either be used separately or in combination.

**Ozone**

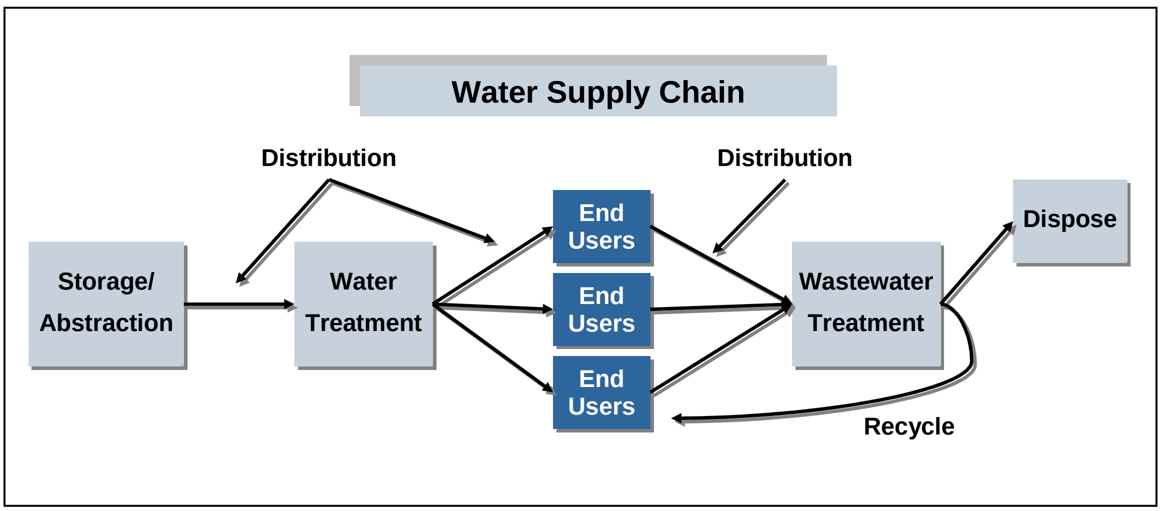
Ozone is a highly effective disinfectant, capable of destruction of all known bacterial species and quick inactivation of viruses. In addition, this treatment has the benefits of taste, odour, and colour removal, and is capable of oxidising harmful organic chemicals and toxins. It is administered through a process known as ozonation. This treatment is ten times more effective than chlorination and is the most popular method for treating eutrophic water in South Africa. Research conducted by CJ van der Walt (1997), developed guidelines for its usage to treat eutrophic and coloured waters in South Africa.

**Powdered Activated Carbon (PAC)**

PAC is a form of processed carbon that is very porous and therefore has a large surface area for absorption or chemical reactions. The carbon in the biological treatment process acts as a "buffer" against the effects of toxic organics in the wastewater. The addition of the PAC at the WTW controls color and odour, and may reduce disposal costs while removing soluble organics, including some biological toxins (Linde, Freese & Pieterse, 2003).

**Treatment Costs**

***Figure 9: Overview of Water Supply Chain***




Treatment via either method is conducted at the WTW. Dosage and the associated prices for each treatment method are case-specific and the precise amount administered is contingent on a number of other factors.

The total cost of eutrophication may be estimated, on a best effort basis, according to the costs of treating eutrophic water using PAC in South Africa, per annum. This calculation is purely an example and the actual costs of treatment will depend on a variety of factors. The following assumptions apply in this regard:

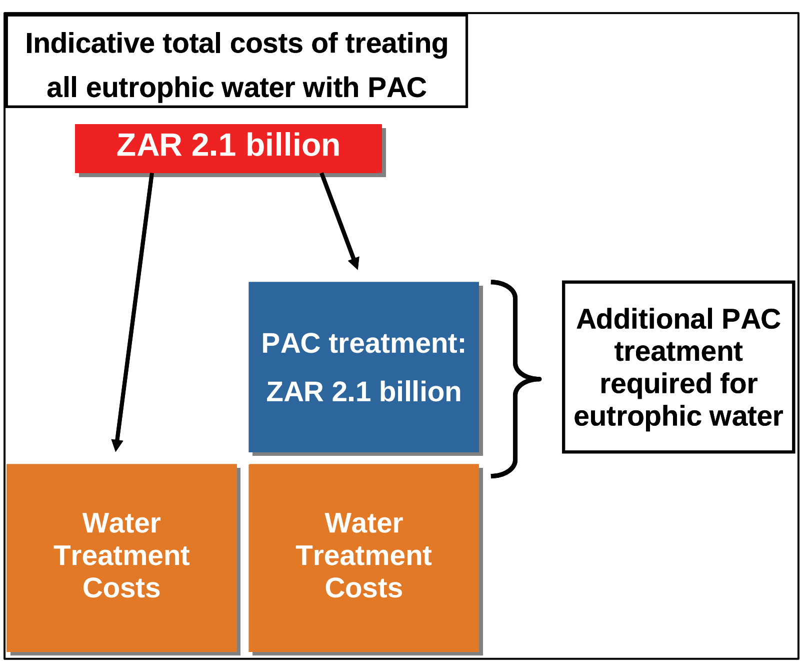
- Total water demand is for commercial, public and household use (water used for industrial and agricultural purposes is not included)
- Thirty five per cent of impounded water in South Africa is classified as eutrophic to hypertrophic, thereby representing that portion of water requiring PAC treatment

*Table 3: Calculating the cost of total Powdered Activated Carbon (PAC) treatment*

| | | |
|---|---|---|
| **Total Water Demand (Commercial, Public & Household)** | **2.5 million megalitres** | 1 |
| **Average cost of PAC treatment / megalitre / annum** | **ZAR 2400** | 2 |
| **Percentage of total impounded water storage classified as eutrophic to hypertrophic in South Africa** | **35%** | 3 |
| **Estimated indication of the extent of water that may require PAC treatment due to eutrophication%** | **875, 000 megalitres** | |
| **Estimated cost of total PAC treatment of eutrophic water** | **ZAR 2.1 billion** | |

1. *Charting our Water Future: Economic frameworks to inform decision making, 2030 Water Resources Group, 2009. Data is from 2005.*
2. *Pers. Comm. City of Cape Town Metropolitan water treatment management., 2009.*
3. *Harding, W et al. An overview of cyanobacterial research and management in South Africa post-2000, July 2009.*

*Figure 10: Indicative total cost of eutrophic water treatment*



Based on these assumptions and this approach, the total estimated cost of treating eutrophic water for potable purposes using PAC is approximately **ZAR 2.1 billion**. Were South African water authorities to treat all potable water sources that are eutrophic with PAC, this would be the approximate economic cost

Where the WRC's eutrophication research can be seen to have an economic impact are the research projects that focus on understanding and limiting the extent of eutrophication in South Africa. Therefore, were the findings from this research to be implemented these treatment costs would be significantly lower.

Examples of such projects include:

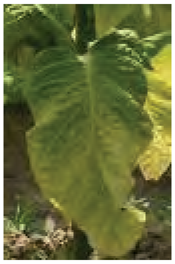
| Report | Report Number |
|---|---|
| *Development of a guide to assess non-point source pollution of surface water resources in South Africa, 1998* | 696/1/98 |
| *Determination of the known extent of cyanobacterial problems in SA water resources, and identification of South African cyanobacterial knowledge, information and research needs* | 1288/1/04 |
| *The development of management-orientated models for eutrophication control* | 174/1/90 |

## ALTERNATIVE WATER SOURCES

### Introduction

South Africa is populated across a spread of urban and rural areas. Whilst people in urban areas typically have better access to treated, running water, a large proportion of the population are found in rural areas with little or no access to running water. These communities rely on water found in nearby dams, lakes and streams. Additionally, a large majority of farms in South Africa rely on water from nearby rivers and lakes for irrigation purposes.

Water contaminated by cyanobacterial blooms is not fit for human consumption and people who rely on a particular water system as a potable water source need to find alternative sources for their daily water requirements (JH O'Keeffe, CE van Ginkel, DA Hughes & TR Hill, 1996). In addition, eutrophic water clogs irrigation systems and requires costly investments from farmers to replace these systems, which motivates these farmers to seek alternative water sources.



**Tobacco Farming**

A significant problem posed by the impact of eutrophication is that South Africa has very few alternative water sources available. In most instances, the option of sourcing alternative water sources simply is not feasible. An example refers to the Hartbeespoort Irrigation Scheme, wherein a tobacco plantation was irrigated via the scheme. The scheme supplies irrigation water through 544 kilometers of canals to farmland in the surrounding areas. Tobacco farming in the area, reliant on the water supplied by this scheme, was all but discontinued as a result of the highly eutrophic water that was supplied. The leaves of the tobacco plants absorbed some of the odours from the contaminated water and this affected the taste of the tobacco (S. Mitchell pers. comm.). This is in addition to the increasing chloride content of the irrigation water, which negatively affected the burning properties and price of the tobacco leaves.

Using the average price of tobacco in 2008, the following table depicts the revenues derived from tobacco farming in South Africa, per annum. The industry makes a significant contribution to GDP, which is threatened by the use of eutrophic water for irrigation purposes.

***Table 4: Potential Revenue Loss from Tobacco Farming***

| Item | Value |
|---|---|
| Total tobacco production (kg) | 34 000 000 |
| Total number of farmers | 1 000 |
| Average output per farm (kg) | 340 000 |
| Average price per kg (ZAR/kg) | 8 |
| ***Total Revenue Lost (ZAR)*** | ***272 000 000*** |

The sourcing of non-eutrophic water is critical for the South African tobacco industry. Insufficient water supplies could have significant economic impacts for the individual tobacco farmers as well as South Africa's economy. The WRC has commissioned several projects that have focused on the eutrophication issues at the Hartbeespoort dam and irrigation scheme with a view to understanding the extent of the problem and suggesting mitigation measures. Examples of some of these projects are detailed below: WRC eutrophication research that addresses the impacts of eutrophic water on tobacco farming includes:

| Report | Report Number |
|---|---|
| *Research on eutrophication in the Hartbeespoort Dam* | - |
| *Research on the evaluation of the impact of the phosphate standard on the water quality and trophic status of Hartbeespoort Dam* | - |
| *Research on the management of phosphate concentrations and algae in Hartbeespoort Dam* | 289/1/92 |

**Bospoort Dam**

Bospoort Dam is situated in the North West Province of South Africa. The impoundment is rated as severely eutrophic and the local WTW is unable to cope with the degree of eutrophication present. Tastes, odours and colours are not able to be removed. As such, costs of **ZAR 400 000** per month are incurred to source potable water supplies from either Rand or Magalies Water boards.

***Table 5: Cost of Using Alternative Water Source at Bospoort Dam***

| | |
|---|---|
| Cost of using alternative sources of water (month) | ZAR 400 000 |
| Cost of using alternative sources of water (year) | ZAR 4 800 000 |

This is just one example of a water service provider that is not able to utilise traditional sources of raw water due to eutrophication, which results in a cost of **ZAR 4 800 000** per annum. The Water Research Commission has conducted numerous research projects focused on reducing the impact of eutrophication and water treatment techniques to treat eutrophic water. Implementation of this research could result in this particular WTW saving these costs. Specific studies that focus on this problem include:

| Report | Report Number |
|---|---|
| *Determination of annual phosphorus loading limits and land use-based phosphorus loads for 30 Key South African dams in relation to their present and likely future trophic status* | 1687/1/08 |
| *The occurrence, distribution and removal of algal species and related substances in a full scale water purification plant* | 567/1/00 |
| *Evaluation of powdered activated carbon (PAC) for the removal of taste and odour causing compounds from water and the relationship between this phenomenon and the physico-chemical properties of the PAC and the role of water quality* | 1124/1/03 |

## AGRICULTURAL IMPACTS

### Introduction

South Africa is heavily reliant on its primary agriculture production, which contributes approximately 15% to annual GDP levels (McKinsey, 2009). Agricultural exports constitute 8% of total exports from South Africa. Under the broad definition of agriculture, farming, fishing (aquaculture) and forestry are included. The phenomenon of eutrophication has significant negative impacts on both farming and fishing.

***Figure 11: Farmland using crop irrigation***

**Loss of Fish Stocks**

South Africa's aquaculture industry contribution to GDP is more than ZAR 140 million per annum. The country contributes 0.5 per cent towards the total, international annual catch.

Although there is no significant freshwater fishing conducted for commercial use in South Africa, eutrophic water has far reaching effects for any fish life, which then have knock-on effects through the entire ecosystem. Many farms in South Africa rely on fish species to control aquatic biodiversity and many communities rely on the fish as a sustainable source of protein. Eutrophication leads to desirable fish stocks being replaced by less desirable species. Fish living in water which has severe levels of eutrophication die due to the depletion of dissolved oxygen. A reduction in harvestable shellfish can also occur. This is when shellfish, such as freshwater or saltwater mussels, are attached to rocks alongside estuaries carrying contaminated water. The filter-feeding shellfish then become contaminated and unfit for human consumption. Fish, such as trout, cultured in algal rich ponds, may become tainted with cyanobacterially-produced taste and odour compounds.

This phenomenon has had severe implications for trout production in South Africa. South Africa produces approximately 1400 tons of trout per annum, of which the Western Cape produces some 450 tons and Mpumalanga about 600 tons. Trout production is valued at between ZAR 7.00 and ZAR 9.00 per kilogram, with a total industry value of **ZAR 12.6 million** per annum. The impact of eutrophication on trout farming would therefore be significant if left untreated.

***Table 6: Potential Production Loss from Trout Farming***

| | |
|---|---|
| **Trout produced (kg)** | **1 400 000** |
| **Productions costs (ZAR/kg)** | **9** |
| **Total production (ZAR)** | **12 600 000** |

*Figure 12: Fish Kills due to Eutrophication*

**Improving Irrigation on Farmland**

Approximately 1.7 million hectares of land is irrigated in South Africa for crop production. Irrigated agriculture accounts for 62 per cent of water use in South Africa, the largest proportion. Should a water supply reservoir contain cyanobacterial blooms and toxins, the exposure of crops to these toxins through spray irrigation or watering may result in the accumulation of toxins in plant tissues. European Union import controls prohibit the importation of crops irrigated with water containing cyanobacteria, which can have a significant impact on South African crop exports.

Additionally, eutrophic conditions can result in an outbreak of aquatic weeds, which clog irrigation canals and pipes. Given that 75% of irrigated areas are served through sprinklers and drip irrigation devices, replacement of pipes can be a very costly exercise. Du Plessis & Steyn (2003) suggest the application of triploid grass carp in irrigation canals as a biological control agent for the problem of weed growth, whilst AR Wood (2003), suggests an aquatic plants species, *pythium,* as a further control measure.

*Figure 13: Agriculture and irrigation statistics*

| | |
|---|---|
| **Contribution of agriculture to annual GDP** | **15%** |
| **Proportion of total water supply used for agricultural irrigation** | **62%** |

*Figure 14: Clogged irrigation pipe*

*Figure 15: Triploid grass carp being added to an irrigation canal*

### Losses incurred from animal deaths

Since 1913 to present day, there have been many cases reported of livestock and other wildlife fatalities, as a direct result of cyanobacteria poisoning, in South Africa. Specifically, there are annual reports of animal death from many of the dams in the Crocodile West/Marico and Olifants River Water Management Areas (WMAs), with occasional reports from the Middle and Lower Vaal and Lower Orange WMAs. In 1996, 400 pregnant dairy livestock died as a result of consuming water affected by eutrophication in the Kareedouw District of Tsitsikamma. The cattle died from cyanobacteria poisoning. Each cow is estimated to be worth **ZAR 10 000** when pregnant.

*Table 7: Stock Losses incurred at Kareedouw as a result of cyanobacteria poisoning in 1996*

| | |
|---|---|
| **Pregnant Dairy Cattle (value per cow)** | **ZAR 10 000** |
| **Total Cattle Deaths** | **400** |
| **Total Loss** | **ZAR 4 000 000** |

From these examples it is clear that eutrophication is and can have a significant impact on South Africa's agricultural sector. The WRC has conducted both agricultural specific eutrophication research as well as studies that focus on the broader issue of eutrophication. The implementation of the findings from these research projects could have an important impact for South Africa's agriculture sector. Examples of these reports include:

| Report | Report Number |
|---|---|
| *The use of triploid grass carp as a biological control measure for excessive water weed growth in irrigation systems* | 816/1/03 |
| *The effective use of water by means of an algal aquaculture system* | 182/1/89 |

**Conclusion**

Use of the WRC's eutrophication research by industry has resulted in economic impacts, such as an increased focus on establishing nutrient standards, which has led to the improved treatment of eutrophic water and an associated reduction in animal fatalities and human illness. The economy has already benefited indirectly from the research via certain recommended applications, such as the use of triploid grass carp in irrigation canals.

The economic costs associated with not treating eutrophication are vast and have far reaching impacts. Through its eutrophication-focused research, the WRC has identified the necessity of treating water that has been affected by this phenomenon and methods for the prevention of eutrophication. It has also focused on the process and cost of seeking alternative water sources, as well as highlighting the implications that eutrophication has for agricultural practices.

### 3.3.3 Case Studies

**CASE STUDY: TREATMENT AT A LARGE WTW**

The following is typical WTW data, obtained from one of South Africa's largest metropoles, with regard to treating the phenonmenon of eutrophication:

The WTW spends an average of R1 800 000 per month on water treatment. It draws its water from two main dams, one of which has significant levels of eutrophication. The WTW employs the treatment method of PAC on an infrequent basis. For the past 5 years, they have not used any of their PAC stock. During 2009, they have used their entire stock of PAC.

However, due to the additional cost of this treatment, at approximately R75 000 per month, the WTW has chosen to mix the eutrophic water with the uncontaminated water from the second dam in order to reduce the taste and odour problems. This is a short-term solution that is not sustainable and the WTW will soon need to employ chemical treatment methods, aimed specifically at removing the effects of eutrophication, on a permanent basis.

**EXAMPLE: UPGRADING WATER TREATMENT WORKS**

Eutrophication is a critical problem and a large number of South Africa's lakes and water bodies have already been affected. Whilst the available treatment methods are effective in removing tastes, odours and toxins from contaminated water supplies, these methods address the symptoms of the problem and are unable to prevent it from occurring. They also need to be employed constantly, which is very costly. In order to ensure that eutrophication is brought under control and eventually eradicated, prevention methods need to be implemented. The most effective prevention method, acknowledged and followed globally, is to remove phosphorus – a leading cause of eutrophication – at the waste water treatment works (WWTW). Phosphorus is one of the major nutrients contributing to the increased eutrophication of lakes and natural waters. Globally, certain countries have developed legislation which controls the maximum amount of phosphorus allowed to be discharged from a WWTW. This prevents the phosphorus from being released back into water bodies.

**Process and Costs of Prevention**

The process to be followed to prevent eutrophication in South Africa is threefold – initially, the major WWTW require an infrastructure investment to bring them to normal operation standards. Research conducted by O'Keeffe, van Ginkel, Hughes & Hill (2008) confirmed that most WWTW are overloaded and do not have the capacity to meet the demand in their respective metropoles. The investment to upgrade the WTTW infrastructure to normal operation levels is approximately **ZAR 200 million** for a typical metropolitan WWTW.

The second phase of implanting a prevention program is to further upgrade the WWTW to a biological nutrient removal (BNR) stage. BNR acts to remove phosphorus from waste water at the WWTW. Controlling phosphorus discharged from municipal and industrial wastewater treatment plants is a key factor in preventing eutrophication of surface waters. Approximately 40 per cent of wastewater phosphous discharge is caused by detergents, as discussed by Pillay & Buckley (2001). It has been estimated that to upgrade a large WWTW to facilitate BNR will cost an additional **ZAR 200 million**.

Once these infrastructure upgrades have taken place, employing BNR is estimated to cost **ZAR 1.50 per 0.001 ML** of water treated, depending on the nature of the effluent being treated and size of the treatment works.

A few of the benefits to be derived from preventing eutrophication include:

- Improved and sustainable biodiversity
- Decreased loss of animal life
- Decreased reliance on costly chemical treatment methods
- Improved agricultural yields
- Improved land and property values

***Table 8: Cost of Eutrophication Prevention***

| | Process | Cost (ZAR) |
|---|---|---|
| **Phase 1** | Upgrade WWTW to normal operation levels | **200 000 000** |
| **Phase 2** | Upgrade WWTW to facilitate BNR | **200 000 000** |
| **Phase 3** | Operational cost of BNR treament | **1 500/1ML** |

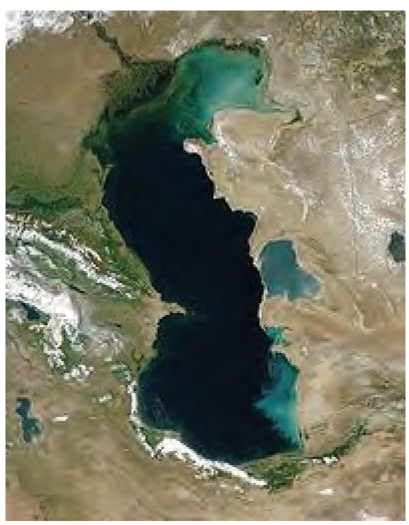
## 3.4 Environmental Impacts

### 3.4.1 Introduction

Southern Africa is an arid to semi-arid region with an average annual rainfall of just under 500mm. South Africa's exploitable water supplies are confined to rivers, artificial lakes and groundwater. Total South African runoff is estimated at 53 500 million cubic meters, of which approximately 33 million cubic meters could be used. Gauteng's urban complexes, such as Pretoria and Johannesburg, generate significant amounts of sewage on a monthly basis.

This gives rise to effluents that have a high phosphate and nitrate content, which then stimulate the growth of cyanobacteria in lakes, rivers and reservoirs. This results in eutrophication, which has far reaching negative consequences for the environment. Water affected by eutrophication may even be seen from space.

***Figure 16: Eutrophication in the Caspian Sea as seen from space***



The WRC's research has explored the impacts that eutrophication has on the environment. The research has aimed to both identify the impacts and to suggest means for alleviating or avoiding these negative consequences, through the treatment and prevention of eutrophication. One report, conducted by TG Downing (2007), developed a model for the environmental regulation of the toxins produced by cyanobacteria, which have far-reaching negative impacts on wildlife and the environment. This model outlined measures to reduce these impacts.

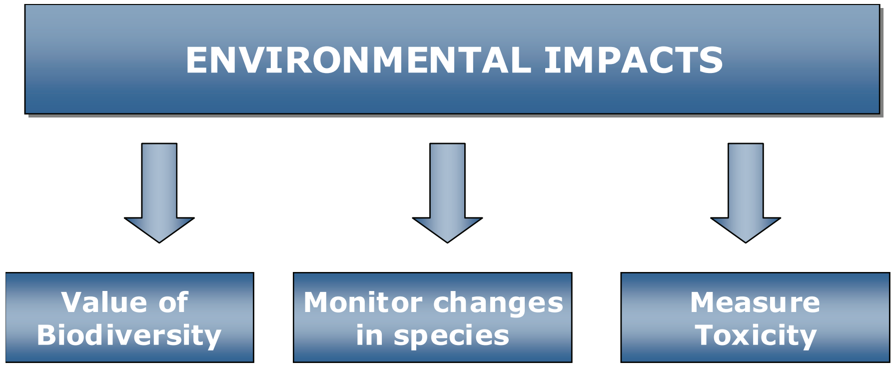
Further examples of the WRC's research, aimed at raising awareness about the negative impacts of eutrophication on the environment, are listed below along with the impacts to be explored by this research analysis.

***Table 9: Examples of WRC Reports on the Environmental Impacts of Eutrophication***

| Report | Study |
|---|---|
| TT153/01 | Cyanobacteria: A Review |
| 1401/3/07 | Environmental factors affecting the persistence of toxic phytoplankton in the Hartbeespoort Dam |
| TT277/06 | A research strategy for the detection and management of algal toxins in water sources |

The eutrophication research conducted by the WRC has had several environmental impacts, which may be classified into three broad categories, namely the value of biodiversity, monitoring changes in species and to measure toxicity.

***Figure 17: Overview of Environmental Impacts***



### 3.4.2 Quantification and Qualification of Impacts

**VALUE OF BIODIVERSITY**

Biodiversity in an ecosystem is crucially important. It refers to the number and variety of plant and animal life within a particular ecosystem. When an aquatic ecosystem experiences an increase in nutrients, primary producers such as algae experience a population increase. These algal blooms decrease the amount of sunlight available for bottom-dwelling species and can significantly decrease the amount of dissolved oxygen in the water. WRC-funded research emphasises the value of biodiversity as a critical goal in the majority of their eutrophication-related studies.

When oxygen levels have been depleted, fish and other marine animals suffocate, leading to the death of fish, shrimp and immobile bottom dwellers. The ability of eutrophication to lower the ecological integrity of an aquatic ecosystem means that only the most tolerant of species survive, of which there are very few.

**Dredging clean-up costs**

Natural assets, such as aquatic ecosystems, have value as purifiers and collectors of waste. They essentially act the role of natural water treatment plants and sewage outfalls. As with their built infrastructure counterparts, however, these systems can only cope with a certain amount of waste before becoming inefficient. The constant over-production of algae, accompanied by the death of these blooms and the subsequent accumulation of dead plant matter and aquatic animal life, leads to a water body becoming silted up and highly eutrophic.

Zeekoevlei, a vlei situated in the densely populated Cape Flats area in the Western Cape, is an example of a water body that has been abused to the point where it has arguably become a liability. The vlei is plagued by noxious and toxic algal blooms, which have stunted the development of its biodiversity and impaired its ecosystem health.

*Figure 18: Zeekoevlei, Western Cape*

The only option to handle the severity of the situation is to completely dredge the vlei. Dredging is considered an expensive option in addressing eutrophication. However, given that the elevated levels of phosphorus in the sediment aggravate the eutrophication problem, controlled sediment removal is often unavoidable in severe cases such as this. It is estimated that the minimum cost of dredging the vlei will be **ZAR 60 – 70 million**, in order to restore the vlei to normal levels.

**Dredging Cost** | **ZAR 60 – 70 million**

Research conducted by the WRC on the phenomenon, sources and management of eutrophication has assisted Cape Town water authorities with the understanding of the extent of the problem as well as supported the development of a remediation strategy at Zeekoevlei. Through the implementation of the research findings these dredging costs can be avoided in the future, which will provide a significant saving for the City of Cape Town and help improve the environmental integrity of the Zeekoevlei system.

## MONITOR CHANGES IN SPECIES

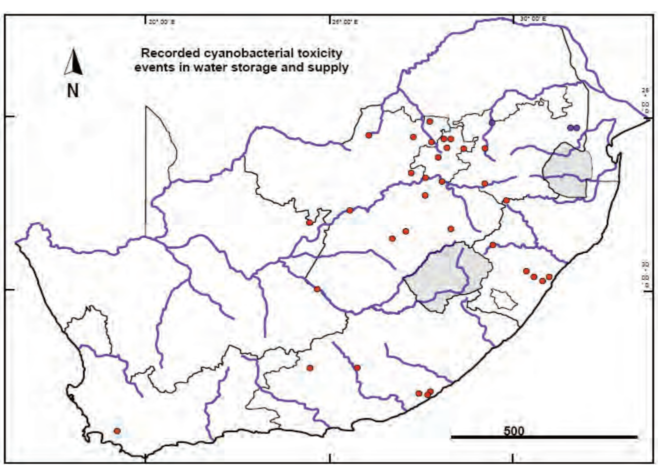
The growth of micro-organisms in an aquatic ecosystem is limited by the presence of that nutrient which is required most for development. This is known as the limiting nutrient theory. The phenomenon of eutrophication makes the presence of phosphorus and nitrogen, both of which are limiting nutrients, abundant in an aquatic ecosystem. This leads to a shift in the species composition of ecosystems, wherein new competitive species out-perform the original inhabitant species.

The WRC's body of eutrophication-related research has addressed the importance of monitoring changes in species in order to detect eutrophication. The research has an impact where such information will be applied by water management authorities. According to a research study, conducted by Madikizela, Dye & O'Keeffe (2001), the variety and nature of species within a certain catchment provide an important indicator for environmental change, including the presence of eutrophication, and should be closely monitored. The eutrophication of Lake Constance, Germany in the 1970s and 1980s led to genetic changes in a species of water flea which was ultimately displaced. Although the lake has since been rehabilitated, the water flea has not re-established.

## MEASURE TOXICITY

Certain algal blooms are toxic to plant and animal life. The toxins produced are able to make their way up the food chain, resulting in ultimate animal mortality. When the algae are ruptured or eaten, they release toxins which are poisonous to animals and humans alike. The results are usually fast, with large numbers of animal mortalities. The research conducted by the WRC addressing toxicity, such as that of TM Downing (2007), identifies the nature and scope of the toxins produced by cyannobacteria, and the implications for the health of all water users. It emphasizes the need to measure toxicity levels to prevent fatalities.

***Figure 19: Recorded cyanobacterial toxicity distribution which caused animal death***



The Olifants River, which runs through the Kruger National Park, is one of South Africa's least healthy river systems. The river is subject to high levels of pollution caused by human overuse and subsequently has significant levels of eutrophication (DWAF, 2008). There have been numerous reports of animal deaths in and around reservoirs in the park, as well as at Loskop Dam.

The Kruger National Park is a world-renowned tourism destination, attracting more than 40,000 visitors per annum and generating an annual turnover, attributable to the river systems specifically, of approximately **ZAR 41 million** per annum (Turpie & Joubert, 2001). A significant attraction of the park is the many river systems which are home to a variety of wildlife. Animal deaths, due to consumption of eutrophic water, could give the park a poor reputation and may discourage tourists from visiting. This will have negative impacts on the park's revenues and ultimately on the tourism industry in South Africa. It is estimated that should Kruger's rivers become totally degraded the park would lose approximately 30% of its revenue.

| Loss of Kruger National Park tourism revenue in the event rivers were totally degraded | - 30% |
|---|---|

WRC research, conducted into the phenomenon of eutrophication, may be seen to have an environmental impact in the understanding and limiting of the occurrence and extent of eutrophication in water systems. The implementation of the research findings would assist with mitigating and limiting the impact of eutrophication on South Africa's environment. Examples of such research include:

| Report | Report Number |
|---|---|
| *A Guide to catchment-scale eutrophication assessments for rivers, reservoirs and lacustrine wetlands* | TT352/08 |

**Conclusion**

The effective and targeted use of the WRC's eutrophication research is likely to reduce and even remedy the incidence of the environmental impacts discussed above. The research addresses the value of biodiversity, which eutrophication threatens. It also highlights that a change in species in an ecosystem is indicative of a problem, which may include eutrophication. Guidelines are provided for measuring toxicity levels in a eutrophic system, to avoid animal fatalities. Focus on sustaining biodiversity and desirable species in an area will have far reaching impacts for each ecosystem, and the goods and services derived from it. In the long term, this focused approach may even significantly reduce the costs associated with rehabilitating an area.

### 3.4.3 Case Studies

**CASE STUDY: REHABILITATION OF HARTBEESPOORT DAM**

Hartbeespoort Dam is situated in the North West Province of South Africa, surrounded by residential and commercial developments and a popular recreational destination. The dam is subject to rapid, human induced nutrient fluctuations which are not caused by natural environmental conditions. Hartbeespoort has been shown to have severe algal and cyanobacterial blooms, with its eutrophication level rated as serious. This poses a threat to the biodiversity of the dam, its associated property values and the health of animals and people who come into contact with the water.

The Hartbeespoort Dam Rehabilitation Programme aims to remedy the severity of the situation at the dam. The proposed interventions and associated costs are given below The entire project is valued at an expected ZAR 180 million, which is divided over a number of years according to fixed and variable costs as follows:

| | **Costs (ZAR/annum)** |
|---|---|
| **Fixed costs** | |
| *Infrastructure establishment:* | *1 200 000* |
| *Algal, hyacinth, debris and litter removal:* | *1 800 000* |
| *Remediation of shoreline and floating islands:* | *2 900 000* |
| *Food-web restructuring:* | *2 800 000* |
| Sub-total | 8 700 000 |
| | |
| **Variable costs** | |
| *Running costs:* | *3 600 000* |
| *Management fees:* | *2 400 000* |
| Sub-total | 6 000 000 |
| | |
| **Grand total per annum** | **14 700 000** |

There are plans to implement a similar programme at Roodeplaat Dam.

## 3.5 Social Impacts

### 3.5.1 Introduction

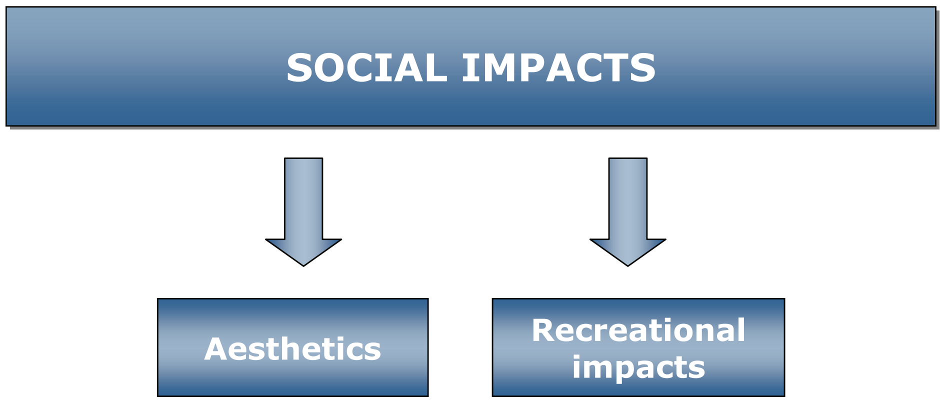
The phenomenon of eutrophication has various and far-reaching impacts on society. Many elements of natural landscapes, such as the presence of water and vegetation, continue to be associated with a high preference and strong aesthetic value. In comparison, built features, degraded landscapes and polluted water systems are consistently associated with low preferences. Many researchers, local and international alike, also believe that there is a direct relationship between the biodiversity and health of an ecosystem, and the perceived beauty and sense of place of that landscape.

Eutrophication results in water bodies that have a thick and unsightly pea-soup appearance and texture, with unpleasant odours. Due to the toxic nature of the algal blooms, people may be forced to find water at alternative sources. People that come into contact with the water may become ill and many recreational activities are threatened or cancelled as a result.

Research conducted by the WRC, which addresses these social impacts, has included studies that explore the assessments of water resources to provide early warning systems. One such study, conducted by HL Malan & JA Day (2005), considers the assessment of trophic status in aquatic resources, with particular reference to the water quality reserve. A further study, conducted by WR Harding, JN Roussouw & OS Fatoki, (2008), provides a guide to catchment-scale eutrophication assessments for rivers, reservoirs and wetlands. The guide includes an assessment protocol and training course which will allow for the education of all stakeholders about eutrophication, from professional practitioners to local communities.

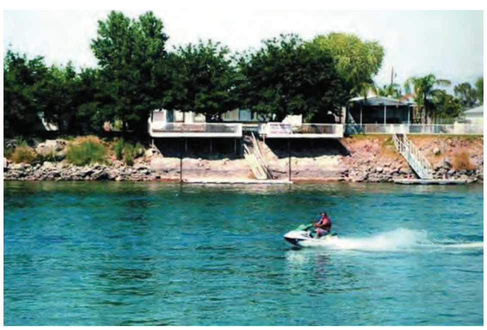
The social impacts realized from the use of WRC research into eutrophication may be segmented into aesthetic impacts and recreational impacts respectively.

*Figure 20: Overview of Social Impacts*




**3.5.2 Quantification of Impacts**

**AESTHETIC IMPACTS**



Many of the dams, rivers and lakes affected by eutrophication in South Africa have residential properties surrounding them. The surface scums and algal blooms that occur as a result of this phenomenon are unsightly and often lead to noxious odours. These symptoms of eutrophication affect the aesthetics of an area and make it highly unpleasant to live near affected water bodies.

Given the subjective nature of an aesthetic, this impact is impossible to quantify. It does, however, greatly affect people's decisions regarding the areas where they choose to live and socialise. This, in turn, affects property and recreational values in the area.

**Property Values along the Vaal River**

The Vaal River is South Africa's single-most important river, contributing more than 20 per cent towards GDP levels, according to the South African Government. The river supports the largest gold mining industry in the world, as well as serving the coal mining, agriculture, manufacturing and paper industries which surround it. Given that the Vaal has a large catchment area, a significant amount of nutrients are released into the river system. This has led to high levels of eutrophication.

The deteriorated water quality has had visible impacts on residential property values along the river banks. Typically, residential units with a waterfront have higher prices than comparable properties without a waterfront. International surveys conducted to examine the determinants of property purchasing decisions, amongst waterfront property owners, identified that 76 per cent of respondents were very interested to know the quality of the water before purchasing their property. Of these respondents, 97% ranked water quality as an important factor. Further international studies have shown that a 0.1 meter decrease in water clarity can lead to a 0.9 to 6.0 per cent decrease in average property values. A study of Vaal River properties (Mostert, 2009) showed that a 1% increase in ammonium nitrate, a leading cause of eutrophication, decreased property values by 0.26% respectively.

This case indicates that eutrophication in the Vaal will impact property prices. Where the WRC has influenced this is through a number of WRC-funded research projects that have addressed the problem of eutrophication at the Vaal River. The research findings have suggested remedies and courses for action for water managers. Examples of such reports include:

| Report | Report Number |
|---|---|
| *Eutrophication levels of some South African Impoundments* | Water SA Vol. 2 No. 2 |
| *Water Pollution: Predicting the development of harmful algal blooms* | WRC Technical Brief |

## RECREATIONAL IMPACTS

### Introduction

The tastes, noxious odours and toxins caused as a result of eutrophication have a significant impact on water-reliant recreational activities, such as swimming, rowing, fishing and boating. Fish mortalities, common with high levels of eutrophication, also add to making an affected water body an unattractive recreational destination.

Two of South Africa’s most popular recreational dams, namely Hartbeespoort and Roodeplaat, have been plagued by eutrophication for many years. As a result, certain recreational events, such as rowing regattas, have been cancelled or moved to different venues.

### Dusi Canoe Marathon

The Dusi Canoe Marathon (Dusi) is one of South Africa’s greatest canoeing events, taking place annually along the Mzundusi River between Pietermaritzburg and Durban. The race attracts approximately 2 000 paddlers, with an additional 2 000 to 3 000 seconders, supporters and helpers.

In the Pietermaritzburg region, the river occasionally contains very high counts of faecal contamination which causes eutrophication levels to rise. This has resulted in a fairly high incidence of health issues amongst canoeists participating in the events. These include diarrhea (referred to as "Dusi guts"), as well as eye and ear infections, and septic cuts. The poor quality of water is believed to be caused by sewers near the river overflowing during heavy rains, and illegal dumping. The annual canoe marathon, estimated to be worth **ZAR 30 000 000** in equipment and accommodation costs and **ZAR 100 000 000** in marketing costs, is constantly under threat from these health risks.

***Figure 21: Warning of polluted water along Mzundusi River***

**Rowing at Roodeplaat**

Roodeplaat Dam is arguably one of the most popular dams for recreation in South Africa. WRC research (Pearce, 1987) has shown that, due to poor water quality and the presence of eutrophication, an invasive alien plant species, water hyacinth, can completely cover the surface of a dam. Although water hyacinth has been shown to control eutrophication, if the hyacinth population itself is not strictly monitored and removed it begins to invade a water body. As the hyacinth covers the surface, it emphasises the effects of the already-present eutrophication, reducing oxygen levels and resulting in taste, odour, colour and turbidity issues. This has occurred at Roodeplaat, restricting fishing, swimming, boating and rowing.

Roodeplaat Dam has been regarded as the best rowing venue in South Africa and the Roodeplaat Rowing Club is suffering hugely as a result of the hyacinth problem. Recently, the Gauteng Rowing Championship, due to be held at Roodeplaat, was cancelled.

The average costs of a large regatta can be estimated, in order to assess the loss of income from the cancellation of the event:

***Table 10: Average cost of a large regatta***

| Item | Number of people | Cost per person (ZAR) | Total (ZAR) |
|---|---|---|---|
| Admission Fee | 400 | 40 | 16 000 |
| Food | 400 | 24 | 9 600 |
| Drinks | 400 | 9 | 3 600 |
| T-shirts | 300 | 60 | 18 000 |
| | | | **47 200** |

A cancellation of a large-scale regatta, such as the Gauteng Rowing Championship, means that stakeholders incur losses of approximately **ZAR 47 200**. This excludes the cost of lost sponsorships and potential international recognition and tourism.

Research funded by the WRC has sought to alleviate the impacts that eutrophication may have on recreational activities, through the development of early warning systems and measures for educating stakeholders about the problem. Such research has included:

| Report | Report Number |
|---|---|
| *A research strategy for the detection and management of algal toxins in water sources* | TT277/06 |
| *Environmental factors affecting the persistence of toxic phytoplankton in the Hartbeespoort Dam* | 1401/3/07 |

**Conclusion**

Significant improvements in society's standard of living could be realized through the utilisation of WRC's eutrophication research. The major benefits associated with these impacts would be increased waterfront property values, sustainable sporting events which attract local and international spectators and an improved sense of place for all individuals making use of a water body for recreational purposes.

**CASE STUDY 1: FISHING ON THE VAAL DAM**

The Vaal dam is a popular recreational site, used for a variety of amenties such as swimming, picnicking, boating, rowing and fishing. The deterioration of its water quality has had negative impacts on these recreational activites. WRC research has highlighted a strong, negative perception of the Vaal dam as a fishing site. Recreational fishermen have indicated that they find the Vaal dam and immediate river segments' water quality to be poor and unsatisfactory. The fishermen have all but stopped fishing at this site as a result. This had led to knock-on effects, as the families of these fishermen, who used to accompany them for picnics alongside the riverbanks, have also stopped visiting this site.

## 3.6 Health Impacts

### 3.6.1 Introduction

Cyanobacteria produce toxins that can be harmful to human health. Exposure can occur through consumption of toxic water, through skin contact during recreational activities in an affected water body, or through the inhalation of water droplets. A pioneering study, conducted by Grobbelaar, Botes, van den Heever, Oberholster & Oberholster (2004), examined the scope and dynamics of toxins produced by cyanobacteria, in order to better understand the health implications for humans and other water users.

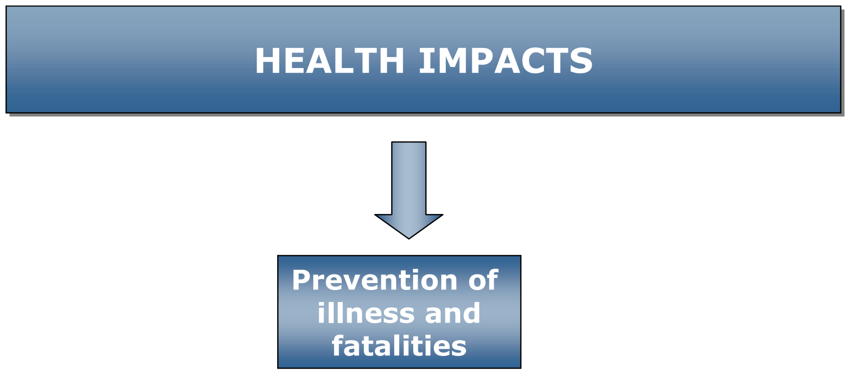
Little information is available on the effects of long-term exposure to cyanotoxins in humans. Incidences of fatal cyanobacterial poisoning in South Africa are widespread but, to date, reports of these poisonings have been restricted to the death of livestock, domestic animals and wildlife. No human fatalities have yet been recorded. Numerous cases of short-term effects of either drinking or coming into contact with infected water have been recorded over the years.

Research funded by the WRC has addressed health-related water quality problems that are caused by eutrophication, as well as highlighting measures to ensure that incidences of poisoning in South Africa are minimised. These research studies include:

| Report | Report Number |
| --- | --- |
| *Development of guidelines for toxicity bioassaying of drinking and environmental waters in South Africa* | 358/1/98 |
| *Algal toxins in drinking water supplies* | 358/1/98 |
| *Situation analysis of health-related water quality problems of the Umtata River* | 549/1/99 |

The paramount impact that the WRC's eutrophication research has had with regard to health is the prevention of illness and fatalities, through identifying and warning against those aspects of eutrophication that have been proven to cause sickness and death.

***Figure 22: Overview of Health Impacts***




### 3.6.2 Qualification of Impacts

Approximately 35 per cent of South Africa's water supply reservoirs have been rated as highly eutrophic, with many more approaching increased levels of severity. As such, a large proportion of South Africa's population is at risk of consuming infected water. In Australia, it is estimated that 600 000 person-days are lost annually through absenteeism caused by cyanobacterial poisoning (Oberholster, Botha & Cloete, 2005).

At greatest risk are rural communities, where poverty levels are almost double those of urban communities. In many instances, there is no other option but to use unsafe water. This problem is compounded by the prevalence of HIV/AIDS in these areas, as people with compromised immune systems are more likely to fall ill from exposure to cyanotoxins. International incidences of cyanotoxin poisoning and fatalities have included:

***Table 11: Global incidence of cyanobacterial poisoning in humans***

| Year | Country | Incidence |
|---|---|---|
| 1992 | United States | Nausea, vomiting, diarrhea, fever, eye, ear and throat infections are experienced after exposure to cyanobacteria |
| 1995 | Australia | Diarrhea, vomiting, flu symptoms, skin rashes, mouth ulcers and fevers experienced 2-7 days after exposure to cyanobacteria |
| 1996 | Brazil | 126 patients were accidentally exposed to cyanotoxins during dialysis treatment, wherein 60 patients died as a result |

**Conclusion**

The eutrophication-related research funded by the WRC has highlighted those aspects of eutrophication which can affect the health of all communities. This research can have far reaching and positive impacts on the health of South African society if it is applied by industry. The most significant impacts of the research include prevention of illness, reduced work absenteeism, improved income to families and companies and avoidance of fatalities.

### 3.6.3 Case Studies

**CASE STUDY: CYANOTOXIN POISONING AT BOSPOORT DAM**

Bospoort Dam is a small, state-owned impoundment situated along the Hex River in the North West Province. The dam is used for both irrigation and domestic water supply. The dam's eutrophication status is currently rated as hypertrophic and the water is subject to taste, colour and noxious odour problems. The Bospoort Water Treatment Works is unable to cope with the level of eutrophication and potable water is subsequently sourced from either Rand Water or Magalies Water.

Various rural communities live near to the shores of Bospoort Dam and draw water from the lake, often without other option. These people experienced an outbreak of diarrhea in 1999 that was found to be linked to a species of cyanobacteria, which resulted in the poisoning of the people who consumed the water.

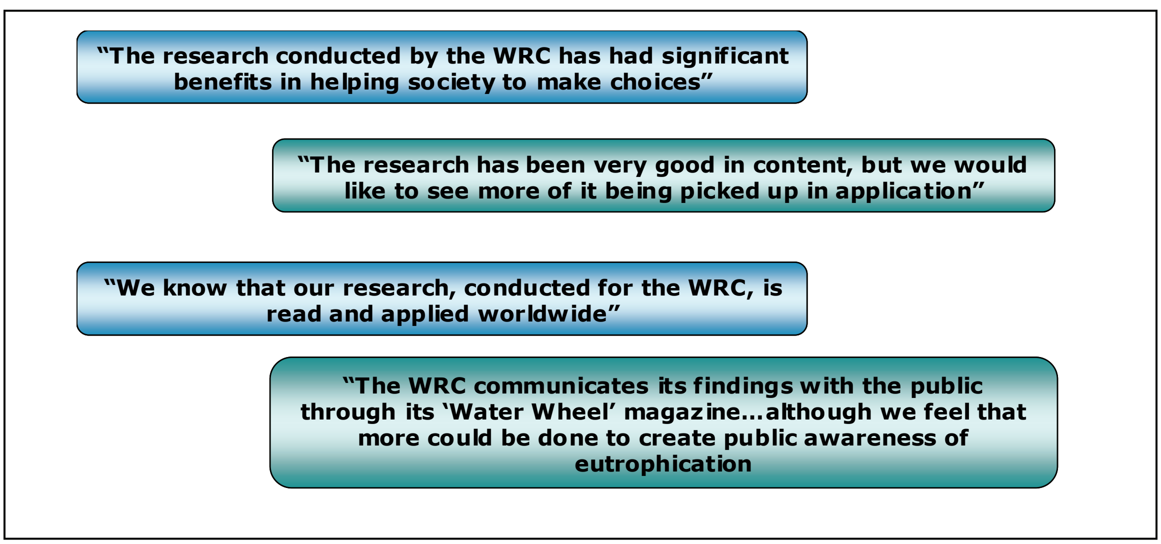
# 4. Conclusion

Since 1984, the Water Research Commission (WRC) of South Africa has been conducting research into eutrophication. The commission is viewed as a dynamic hub for water-centered knowledge, innovation and intellectual capital. The WRC has provided leadership for research and development through the support of knowledge creation, transfer and application. It has engaged various industry participants in solving water-related problems which are critical to South Africa's sustainable development and economic growth.

In order to retain its standing with various industry participants, the WRC has embarked on this study with the aim of quantifying and qualifying the current and potential impacts of their eutrophication-related research. Emphasis has been given to **economic**, **environmental**, **social** and **health impacts**.

As part of this study, various key figures were contacted to discuss their views on the overall impact and application of the WRC's eutrophication-related research. A summary of their responses is provided below:

***Figure 23: Summary of participant responses***



A summary of the impacts identified during this project are provided below:

| ECONOMIC IMPACTS | | |
|---|---|---|
|  | **Treatment Measures** | Ozone |
| | | PAC |
| | | |
| | **Alternative Water Sources** | Tobacco Farming |
| | | Bospoort Dam |
| | | |
| | **Agricultural Impacts** | Fishing |
| | | Irrigation |

With regards to economic impacts, the WRC research addresses treatment measures, seeking alternative water sources in the event that the current source of water is eutrophic, and various agricultural impacts of eutrophication.

| ENVIRONMENTAL IMPACTS | | |
|---|---|---|
|  | **Value of Biodiversity** | Dredging of lakes |
| | | |
| | **Monitor Changes in Species** | Indicators of poor water quality |
| | | |
| | **Measure Toxicity** | Animal deaths |

The environmental impacts examined by the research included emphasizing the value of biodiversity and how the phenomenon of eutrophication can threaten it. The research also highlighted that changes in species can indicate poor water quality and other problems. The studies motivate for the measurement of toxicity levels, in order to prevent animal fatalities.

| SOCIAL IMPACTS | | |
|---|---|---|
|  | **Aesthetic Impacts** | Sight, smell, taste |
| | | Property values |
| | | |
| | **Recreational Impacts** | Dusi Marathon |
| | | Rowing at Roodeplaat |

Social impacts examined by the WRC research included the aesthetic and recreational impacts that eutrophication has had in South Africa. South Africa has a great reputation as a tourism destination, with many water-based recreational activities available, and the losses incurred from canceling or closing such events are discussed and quantified.

| HEALTH IMPACTS | | |
|---|---|---|
|  | **Prevention of illness and fatalities** | Reduced illness and death, leading to less cases of absenteeism and improved family incomes |

The health impacts discussed revolve around the prevention of illness and fatalities as a result of exposure to toxic, eutrophic water. The research details all possible illnesses, their precise causes, and measures for minimizing the incidence of illness and potential fatalities in South Africa.

In conclusion, all of the impacts identified and analysed during this project reflect that WRC research on eutrophication has made positive steps towards improving all aspects of South Africa society. Consistent research, supported by the targeted application by industry of the results and more efforts to increase public awareness, will do a great deal towards eradicating the problem of eutrophication and ensuring a safer, more sustainable future for people, animals and ecosystems alike.

## Appendix: List of published WRC Reports subdivided into research categories

**Category 1: The phenomenon of eutrophication**

- **A preliminary investigation of the effects of water hyacinth on algal growth and water quality** – Pearce, J. (1987). WRC Report No 142/1/87
- **Guide to common filamentous freshwater macroalgae in South Africa** – Bolton, J. & Joska, M. (1994). WRC Report No 66/94
- **Preliminary investigation into algal weeds in inland waters –** Joska, MA. & Bolton, J. (1994) WRC Report No 426/1/94
- **A dynamic model for algal growth in the Vaal River** – Schoombie, S., Cloot, A. & Le Roux, G. (1997) WRC Report No 536/1/97
- **An investigation into phytoplankton blooms in the Vaal River and the environmental variables responsible for their development and decline** – Peterse, A. & Janse van Vuuren, S. (1997) WRC Report No 359/1/97
- **Perspectives on eutrophication of surface waters: Policy/research needs in South Africa** – Walmsley, R. (2000) WRC Report No KV129/00
- **Problem blooms of *cladophora glomerata* and *oedogonium capillare* in South African irrigarion Canals** – Joska, MAP., Bolton, JJ., le Roux, R. (2000) WRC Report No 600/1/00
- **Water quality and faunal studies in the Umzimvubu Catchment, Eastern Cape, with particular emphasis species as indicators of environmental change** – Madikizela, BR., Dye AH. & O'Keeffe, JH. (2001) WRC Report No 716/101
- **The SA diatom collection: An appraisal and overview of needs and opportunities** – Harding, WR., Archibald, CGM., Taylor, JC. & Mundree, S. (2004) WRC Report No TT242/02
- **Assessment of trophic status in aquatic resources with particular reference to the water quality reserve** – Malan, H. & Day, J. (2005) WRC Report No1311/2/05

**Category 2: The sources of eutrophication**

- **Quantification of the effects of Land-use on runoff water quality in selected catchments in Natal** – Simpson, DE. (1991) WRC Report No 237/1/91
- **Non-point source pollution in the Hennops River Valley** – Hoffmann, JR. (1994) WRC Report No 518/1/95
- **A situation analysis of water quality in the Buffalo River, Eastern Cape, with special emphasis on the impact of low-cost, high density urban development on water quality. Volume 1 –** O'Keeffe, JH., van Ginkel, CE., Hughes, DA., Hill, TR., Ashton PJ. (1996) WRC Report No 405/1/96
- **A situation analysis of water quality in the Buffalo River, Eastern Cape, with special emphasis on the impact of low-cost, high density urban development on water quality. Volume 2** – O'Keeffe, JH., van Ginkel, CE., Hughes, DA., Hill, TR., Ashton PJ. (1996) WRC Report No 405/2/96
- **Collection and evaluation of runoff water quality data from a disused feedlot in Natal –** Simpson, DE. (1998) WRC Report No 498/1/98

- **Policy considerations for nonpoint source management in South Africa: as input to the Water Law Review Process** – Pegram, GC., Gorgens, AHM. & Quibell, GE. (1998) WRC Report No 696/1/98
- **Detergent phosphorus in South Africa: Impact on eutrophication with specific reference to the Mgeni catchment** – Pillay, M. & Buckley, CA. (2001) WRC Report No 465/1/01
- **A guide to non-point source assessment to support water quality management of surface water resources in South Africa** – Pegram, GC. & Gorgens, AHM. (2001) WRC Report No TT142/01
- **Development of a nonpoint source assessment guide: Test case studies** – Quibell, G., Pegram, GC., Moolman, J., Matji, MP., Hohls, B. & Gorgens, AHM. (2003) WRC Report No 696/2/03
- **Situation analysis of the health-related water quality problems of the Umtata River –** Fatoki, OS. & Muyima, NYO. (2003) WRC Report No 1067/1/03
- **First order estimate of the contribution of agriculture to non-point source pollution in three South African catchments: Salinity, Nitrogen and Phosphorus** - Cullis, J., Gorgens, A. & Rossouw, N. (2005) WRC Report No 1467/2/05
- **Knowledge review of modelling non-point source pollution in agriculture from field to catchment scale –** Rossouw, JN. & Gorgens, AHM. (2005) WRC Report No 1467/1/05
- **Research on Berg River water management: Summary of water quality information system and soil quality studies** – Gorgens, AHM. & de Clercq, WP. (2005) WRC Report No TT252/05

**Category 3: The management of eutrophication**

- **Impact of eutrophication control measures on the trophic status of South African impoundments –** Grobler, DC. & Silberbauer, MJ. (1984**)** WRC Report No 130/1/84
- **The effective use of water by means of an algal aquaculture system** – Mitchell, SA. (1989) WRC Report No 182/1/89
- **Evaluation of the impact of the 1 mg/l phosphate-P standard on the water quality and trophic state of Hartbeespoort Dam** – Chutter, FM. (1989) WRC report No 181/89
- **The development of management oriented models for eutrophication control –** Rossouw, JN. (1990) WRC Report No 174/1/90
- **The management of phosphate concentrations and algae in Hartbeespoort Dam** – Chutter, FM. & Rossouw, JN. (1992) WRC Report No 289/1/92
- **Utilisation of models to simulate phosphorus loads in Southern African catchments** – Weddepohl, JP. & Meyer, DH. (1992) WRC Report No 197/1/92
- **The application of hydrodynamic reservoir models for water quality management of stratified water bodies in South Africa –** Gorgens, AHM., Bath, AJ., Venter, A., de Smidt, K. & Marais, G v R. (1993) WRC Report No 304/1/93
- **The use of algae in bioassays to detect the presence of toxic compounds in natural waters** – van der Heever, JA. & Grobbelaar, JU. (1995) WRC Report No 393/1/95

- **The management of urban impoundments in South Africa –** Wiechers, HNS., Freeman, MJ., & Howard, MR. (1996) WRC Report No TT77/96
- **The management of urban impoundments in South Africa Vol. 2 –** Freeman, MJ., Howard, MR., Wiechers HNS (2000) WRC Report No TT 119/00
- **The application of hydrodynamic reservoir models for water quality management of stratified water bodies in South Africa: Application of DYRESM and CE-QUAL-W2** – Gorgens, AHM., Bath, AJ., de Smidt, K., & Larsen (1997) WRC Report No 304/2/97
- **The potential for the biological control of the floating aquatic fern, *Azolla filiculoides* Lamarck (redwater fern/rooivaring) in South Africa. -** Hill, MP. (1997) WRC Report No KV100/97
- **Validation of the modified Minlake Model on Roodeplaat Dam** – Venter, A. & Herold, CE. (1999) WRC Report No 785/1/99
- **The potential biological control agents of *cladophora glomerata* that occur in irrigation schemes in South Africa** – Wood, AR. (1999) Report No 669/1/99
- **The extension of management oriented models for eutrophication control** – Rossouw, JN. (2001) WRC Report No 266/1/01
- **The application of triploid carp as biological control agent for the over-abundant growth of aquatic weeds in irrigation canal systems –** du Plessis, BJ. & Steyn, GJ. (2003) WRC Report No 816/1/03
- The **potential of aquatic pythium species for the biological control of *cladophora glomerata* in irrigation schemes in South Africa** – Wood, AR. (2003) Report No 918/1/03
- **Design and development of an implementation plan for a national eutropication monitoring programme** – Murray, K., du Preez, M. & van Ginkel, C. (2005) WRC Report 1147/1/05
- **The determination of annual phosphorus loading limits for South African dams –** Harding, WR. (2008) WRC Report No 1687/1/08
- **The guide to catchment-scale eutrophication assessments for rivers reservoirs and lacustrine wetlands** – Rossouw, JN., Harding, WR., Fatoki, OS. (2008) WRC Report No TT352/08

**Category 4: Blue-green algae**

- **Microcystis scums from Hartbeespoort Dam as a source of fine chemicals –** Batchelor, AL., Scott, WE. & Wood, A. (1992) WRC Report No 264/1/92
- **Cyanobacteria in South Africa: A review** – Harding, WR. & Paxton, BR. (2001) WRC Report No TT 153/01
- **Development of a membrane photobioreactor for the study of microcystin production by cyanobacteria** – Leukes, WD., Strong, J. & Downing, TC. (2003) WRC Report No 1103/1/03
- **Cyanobacteria monitoring 1990 - 2000: Evaluation of SA data** –Downing, TG. & van Ginkel, CE. (2004) WRC Report No 1288/1/04
- **Toxin production by cyanobacteria –** Grobbelaar, JU., Botes, E., van der Heever, JA., Oberholster, A-M. & Oberholster, PJ. (2004) WRC Report No 1029/1/04
- **A research strategy for the detection and management of algal toxins in water sources** – Harding, WR. (2006) WRC Report No TT277/06

- **A model for environmental regulation of microcystin production by microcystis** – Downing, TG. (2007) WRC Report No 1401/1/07
- **Environmental factors affecting the persistence of toxic phytoplankton in the Hartbeespoort Dam** – Owuor, K., Okonkwo, J., van Ginkel, C. & Scott, W. (2007) WRC Report No 1401/2/07
- **The role of nutrient utilisation and photosynthetic capacity in micro-algal bloom formation and the production of cyanotoxins –** du Plesis, S., Kruskopf, MM.m Venter, A. & Conradie. KR. (2007) WRC Report No 1401/2/07
- **Condensed laboratory methods for monitoring phytoplankton, including cyanobacteria, in South African freshwaters** – Swanepoel, A., du Preez, H., Schoeman, C., van Vuuren, SJ. & Sundram, A. (2008) WRC Report No TT323/08
- **PCR based markers for detection and identification of toxic cyanobacteria –** Botha-Oberholster, A. & Oberholster, PJ. (2008) WRC Report No 1502/1/08

## Category 5: Drinking water treatment adaptations

- **The influence of water quality on the efficiency of chlorine dioxide as pre-oxidant and algicide in the production of potable water -** Steynberg, MC., Geldenhuys, JC., Guclielmi, MM., Grobler, S. & Maree, B. (1994) WRC Report No 281/1/94
- **Algal rupture during abstraction from reservoirs and the consequences for water treatment** – Dickens, CWS., Graham, PM. & Freese, S. (1996) WRC Report No 558/1/96
- **Guidelines for the use of peroxone and other oxidants for the treatment of eutrophic and coloured waters in South Africa** – van der Walt, CJ. (1997) WRC Report No 443/1/97
- **Optimization of combined flotation and filtration at a large water treatment plant** – van Beek, JC & Haarhoff, J. (1997) WRC Report No 557/1/97
- **Modelling the water quality in impoundments within the Umgeni water operational area and the consequences for potable water treatment costs –** Graham, PM., Dickens, CWS. & Mbowa, S. (1998) WRC Report No 615/1/98
- **Development of Guidelines for toxicity bioassaying of drinking and environmental waters in South Africa** – Slabbert, JL., Oosthuizen, J., Venter, EA., Hill, E., du Preez, M. & Pretorius, PJ. (1998) WRC Report No 358/1/98
- **Algal toxins in drinking water supplies –** Rae, B., Moollan, RW. & Clark, RC. (1999) WRC Report No 549/1/99
- **The occurance, distribution and removal of algal species and related substances in a full-scale water purification plant** – Pieterse, AJH. et al. (2000) WRC Report No 567/1/00
- **Evaluation of Powdered Activated Carbon (PAC) for the removal of taste and odour causing compounds from water and the relationship between this phenomenon and the physico-chemical properties of the PAC and the role of water quality** – Linde, JJ., Freese, SD. & Pieterse, S. (2003) WRC Report No 1124/1/03
- **Generic incident management framework for toxic blue-green algal blooms, for application by potable water supplies** – du Preez, H. & van Baalen, L. (2006) WRC Report No TT263/06

**Category 6: Development in wastewater treatment to remove phosphorus**

- **Removal of phosphate and nitrogen compounds from biological filter effluents –** Brodisch, KEU. (1985) WRC Report No 58/1/85
- **Enhancement of biological phosphate removal by altering process feed composition** – Osborn, DW., Lotter, LH., Pitman, AR., & Nicholls, AH. (1986) WRC Report No 137/1/86
- **Research into the evaluation optimisation of full scale chemical phosphate removal in biological sewage treatment processes** – Louw, AS., Basson, HJ. & Alexander, WV. (1988) WRC Report No 159/1/89
- **Biological excess phosphorus removal** – Wentzel, MC., Ekama, GA.,Dold, PL., Loewenthal, RE. & Mariais, GvR. (1988) WRC Report No 148/1/88
- **Two year study on the enhancement of biological phosphate removal by altering process feed composition: (Plant and laboratory studies)** – Osborn, DW., Lotter, LH., Pitman, AR. & Nicholls, HA. (1989) (WRC Report No 137/2/89)
- **Two year study on the enhancement of biological phosphate removal by altering process feed composition: (Metabolic control mechanisms)** –Lotter, LH. (1989) (WRC Report No 137/3/89)
- **Phosphate removal from municipal effluents by means of electrochemical coagulant production –** Lempert, GG. & Pretorius, WA. (1990) WRC Report No 287/1/90
- **A comprehensive study on an iron-phosphate removal system** – Momberg, GA. & Oellermann, RA. (1993) WRC Report No 403/1/93
- **Research on biological phosphate removal in activated sludge –** Bosch, M. & Cloete, TE. (1993) WRC Report No 314/1/93
- **Causes and control of Anoxic Aerobic (AA) (or Low F/M) filament bulking in long sludge age nutrient removal activated sludge systems** – Casey, TG., Wentzel, MC., Ekama, GA. & Marais, GvR. (1994) WRC Report No 286/2/94
- **Pilot studies on phosphate crystallisation in biological wastewater treatment systems –** Loots, PA., Oellermann, RA., Pearce, K. & Saayman, GB. (1994) WRC Report No 366/1/94
- **Operation manual for biological nutrient removal wastewater treatment works –** Lilley, ID., Pybus, PJ. & Power, SPB (1997) WRC Report TT 83/97
- **Fingerprinting of activated sludge systems using PAGE analysis of total protein extrections for the optimisation of biological phosphorus removal** – Ehlers, MM., Erasmus, A. & Cloete, TE. ( 1998) WRC Report No 776/1/98
- **Causes and control of low F/M filament bulking in nutrient removal activated sludge systems** – Ekama, GA., Wentzel, MC., Lakay, MT., Pilson, RA., Mellin, HKO. & Casey, TG. (1999) WRC Report No 542/1/99
- **Investigation of the microbial contribution to nutrient removal in an activated sludge wastewater treatment process** – Drysdale, GD., Atkinson, BW., Mudaly, DD., Kasan, HC. & Bux, F. (2000) Report No 822/1/00
- **The treatment of Eutrophic water using pre-and intermediate ozonation peroxone and pica carbon** – Pryor, MJ. & Freeze, SD. (2000) WRC Report No 694/1/00
- **Activated biomass fraction of MLSS and its role in biological phosphorus removal** – Ntshudisane, BM., Oosthuizen, DJ., Ehlers, MM. & Cloete, TE. (2001) WRC Report No 934/1/01

- **Full-scale demonstration of filamentous bulking control at a biological nutrient removal activated sludge plant** – Herculers, S., Tsai, M-W., Lakay, MT., Wentzel, MC. & Ekama, GA. (2002) WRC Report No 823/1/02
- **The treatment of wastewaters with high nutrients (N and P) but low organic (COD) contents –** Musvoto, EV., Ubisi, MF., Sneyders, MJ., Lakay, MT., Wentzel, MC., Loewenthal, RE. & Ekama, GA. (2003) WRC Report No 692/1/02
- **Transforming the PETRO process to provide for biological nutrient removal** – Shipin, OV. & Meiring, PGJ. (2007) WRC Report No 971/1/07

**WRC Eutrophication Research Projects pre-1984:**

- **Kinetics of enhanced phosphorus removal in the activated sludge process** - Martin, KAC and GvR Marais (1975). Report No W 14
- **A Review of eutrophication and guidelines for its control in South Africa. CSIR Special Report** - Toerien, DF (1977) WAT 48, 110 pp
- **Phosphorus removal in the activated sludge process at 14°C** - Vogelzang, W and GvR Marais (1977) Dept of Civil Engineering, UCT Report No W 23
- **Techno-economic survey of eutrophication of the Hartbeespoort Dam** Hofmeyer, HP (1978). WAT 53, 19 pp
- **Part I. Introduction, research summary, management proposals for Swartvlei and recommendations on the use of aquatic macrophytes as nutrient filters** - Howard-Williams, C and Allison BR (1978). IFWS Special Report No 78/2 72 pp
- **Chemical control of the water hyacinth on Hartbeespoort Dam** - Scott, WE, PJ Ashton and DJ Steyn (1979) CSIR Special Report WAT M20
- **The limnology of some selected South African impoundments** - Walmsley, RD and M Butty (1980) Collaborative WRC and NIWR (CSIR) Report. 229 pp
- **Chemical and biological phosphorus removal in the activated sludge process** - Rabinovitz, B and GvR Marais (1980). Dept of Civil Engineering, UCT Report No W 32
- **Guidelines for the control of eutrophication in South Africa** - Walmsley, RD and M Butty (1981). NIWR, CSIR
- **Technical Guide on biological nutrient removal: The Phoredox Process**. Simpkins, MNJP and A Gerber (1982). Water Research Commission Report
- **Research on the optimization of the modified activated sludge process for nutrient removal (1980-1983)** - Ekama, GA (1984) Dept of Civil Engineering, UCT Report No W 52
- **Theory, Design and Operation of Nutrient Removal Activated Sludge Processes** - Water Research Commission (1984) Information document in collaboration with the University of Cape Town, City Council of Johannesburg and the National Institute for Water Research, CSIR
- **The limnology of Hartbeespoort Dam** - National Institute for Water Research (1985) South African National Scientific Programmes Report No 110

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