A REVIEW AND DISCUSSION DOCUMENT

PERSPECTIVES ON EUTROPHICATION OF SURFACE WATERS: POLICY/ RESEARCH NEEDS IN SOUTH AFRICA

RD Walmsley

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Water Research Commission

WATER RESEARCH COMMISSION

A REVIEW AND DISCUSSION DOCUMENT

Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa

Prepared
by

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EXECUTIVE SUMMARY

Section 1 of this report deals with the background to the project and its objectives. This study, sponsored by the Water Research Commission, was initiated as a scanning project to review the topic of eutrophication and assess South Africa's position, with special reference to research and its input to policy. It involved:

- An international scan of countries and organisations to establish the most recent management and policy approaches to eutrophication, and the research that is in position to support these approaches;
- Making contact with some local stakeholders and specialists in order to establish their own concerns and opinions; and
- Preparation of a report on the findings of the scan and the development of a framework as to how, and what, research could assist with the future management of eutrophication in South Africa.

This report contains the findings of these tasks and is intended to act as a discussion document for use by water resource practitioners for the purposes of:

- Understanding the general problem of eutrophication and its management through social, economic and technological approaches;
- Developing appropriate policy;
- Developing approaches to research and monitoring; and
- Developing relevant capacity to deal with the problem.

Section 2 presents a broad overview of concepts on eutrophication, its causes, consequences and control. Eutrophication is a process by which aquatic ecosystems become, over time, progressively enriched with plant nutrients. The enrichment results in an increased production of organic material by aquatic plants (algae and weeds). The process is therefore also associated with the appearance of nuisance plant growths and water resource impairment problems. Eutrophication, caused by enrichment from anthropogenic activities (cultural eutrophication), is a major global water resource problem.

Nutrients originate from a variety of sources, but the most significant sources are materials (consumer commodities, foodstuffs, fuels, detergents, fertilizers, biomass etc.) that are generated by, or used for, major socio-economic activities such as municipal waste management, transport, agriculture and energy generation. Phosphorus and nitrogen have been identified as the key nutrients in the eutrophication process.

Excessive eutrophication is a pollution problem that requires the application of sound waste management principles. The main strategy is for nutrient reduction (primarily phosphorus and nitrogen) via waste minimization and source control, the extent of which is dependent on receiving environment objectives. The involvement of stakeholders and water users in the setting of environmental objectives, and the funding of interventions, is paramount. There are well-established technical interventions for solving eutrophication problems at almost every scale.

The relationship between nutrient inputs and their impacts is extremely complex as there are many factors that can modify (enhance or diminish) the responses of plants to nutrient enrichment. Nevertheless scientists have been able to provide indications of the phosphorus and nitrogen levels above which impairment problems can be expected. In general, the most severe eutrophication problems are experienced in areas where the scale of anthropogenic nutrient inputs far exceeds the capacity of the natural environment to assimilate the waste.

Section 3 represents a scan of the eutrophication problem in countries where it is regarded as a high priority water quality issue. The scan has indicated that eutrophication is a major water resource problem in most of the industrialized countries (e.g. USA, Canada, European Union Countries, and Australia). All of these countries have recognised that the issue is a national strategic problem and have developed appropriate strategies to minimize nutrient inputs into the aquatic environment. The problem does not appear to have as high a priority in less industrialized countries South America, Asia and Africa. In Europe and North America there is a strong environmental and recreational value attached to water resources.

The EEC, Canada, Australia, the USA, and some countries of the European Union (EEC) have all recently undertaken reviews of eutrophication, utilising highly participative and collaborative approaches. They have been able to assess previous policies, quantify the extent of the problem and, through broad participation of society, develop accepted national strategies. These strategies have attempted to mobilise institutions (academic, parastatal, governmental, business and non-governmental) to address the problem. Research and monitoring activities form an integral part of their strategies, and are all geared towards quantifying nutrient sources, their impacts, and assessing the efficacy of policy and its implementation.

The European region is extremely interesting as it has many international water bodies (fresh and marine) and rivers that are common to many countries, both members and non-members of the EEC. Regulatory directives and international agreements on nutrient reduction have been set in place. Some countries of the EEC have been unable to meet their obligations to nutrient reduction targets that were set nearly 10 years ago. Economic and social considerations appear to be the cause of this.

Eutrophication management strategies have been developed to incorporate all aquatic ecosystem types (running waters, standing waters, wetland areas, estuaries and coastal waters). In some countries the nutrient waste management problem is seen as being wider than eutrophication, in that terrestrial ecosystems (wetlands, forests and soils) have been impacted, mainly through atmospheric sources.

It is recognised in the industrialised countries that success to eutrophication management strategies lies in the acceptance of certain perspectives. These include:

- Cultural eutrophication is reversible;
- There is no quick fix. The problem requires a long-term approach;
- The issue requires a collaborative approach between government, business and communities. However, government must play the lead facilitation role;
- The issue cannot be solved by a single technical intervention. The problem requires the implementation of a suite of actions (social, economic and technical); and
- Transparent research and monitoring activities are prerequisites to the decision-making that is required.

Section 4 deals with the situation in South Africa and, based on national policy and legislation, motivates for increased attention to this problem.

Eutrophication, recognised as a priority water resource management problem in South Africa more than 30 years ago, is still widespread. This is particularly so in the more populated industrialized areas of the country. Many water resource management agencies experience the problem on a daily basis in water treatment works and recreational water bodies. The national water resource monitoring system does not allow for any informed opinion as to whether the problem has increased or decreased in intensity.

There is considerable evidence to support the perception that South Africa's policy and approach to eutrophication control has been inadequate over the last 20 years. A lack of input to policy development, monitoring, research, reporting and capacity development has greatly diminished the country's ability to deal with the problem. The apparent low priority given to the issue cannot be ascribed to the absence of any national overarching policy on environmental and water resource management policy. Rather, it has its roots in the inability of government to undertake the required processes that close the gap between policy setting and the required implementation actions.

The National Water Act and the National Environmental Management Act, both promulgated in 1998, carry new perspectives for waste management and eutrophication control. National policy requires that environmental integrity is protected and that waste discharges are minimized. The National Water Act, which is more functional, specifies some of the approaches as to how the gap between policy and implementation can be closed. There is however, a strong need to for the country to remobilize and redevelop its capacity to manage eutrophication.

There are several areas where policy on eutrophication requires a more explicit approach. These include:

- Specifications of a national eutrophication strategy within the National Water Strategy;
- Specifications of a eutrophication strategy within each Catchment Management Strategy;
- Incorporation of eutrophication concepts within the national Classification System for aquatic systems;
- The setting of resource management objectives that include eutrophication-related criteria;
- The incorporation of land-based eutrophication control measures into land management and planning policy;
- The development and dissemination of national eutrophication management guidelines;
- The development and management of a national eutrophication monitoring information management system;
- The development of a long-term research and capacity building programme to support all other activities; and
- The acceptance and commitment of all parties to co-operative governance on eutrophication management and control.

There are numerous research areas that require support. It would be impossible for all of the identified topics to be supported by any one agency. It is felt that immediate national research should be directed at quantitatively assessing: the eutrophication problem in terms of its extent and trends; the sources of nutrients and the levels entering aquatic systems; the actual social and economic costs of the problem on a national basis.

There is a need for South Africa to develop a new approach to eutrophication policy, management and research. It is proposed that this discussion document be used as the basis for an interactive workshop for policy makers that has the objectives of: discussing the report's findings; agreeing on the extent and nature of the "real" gaps in eutrophication policy and its implementation; developing cooperative structures and mechanisms to address the gaps; identifying research priority areas for national support; and, developing a programme of action to ensure that there is follow up to the workshop's findings and recommendations.

1. INTRODUCTION

South Africa has long recognized that water is one of its prime limiting natural resources (Department of Water Affairs 1986; Huntley *et al.* 1987). This has been reflected by policies that led, amongst others to:

- The construction of numerous reservoirs on almost all available river sites throughout the country;
- The construction of many diverse inter-basin transfer systems that transport bulk water from areas of relatively high supply to those of low supply;
- Stringent permit systems for water use and the mandatory return of all effluents to river courses; and
- A permit system for effluent discharges with associated standards and receiving water quality guidelines.

Although designed to satisfy the country's development needs in terms of supply to water users, these practices led to numerous widespread negative environmental impacts (Department of Water Affairs 1986). Some of the main impact areas include:

- Increased nutrient enrichment (eutrophication) of surface waters;
- Increased salinisation of surface and groundwaters; and
- Changes to ecological habitat and a lowering of aquatic biodiversity

Nutrient enrichment of surface waters from anthropogenic sources (cultural eutrophication) has long been recognized as a global water resource problem (Vollenweider 1968; United States Environmental Protection Agency (EPA) 1999; European Environmental Agency (EEA) 1999). It is most often found in highly populated and developed areas where water-borne sewage systems and agricultural practices contribute to elevated loads of nutrients into receiving natural water systems. The nutrients promote the development of both living and decaying biological material in the receiving systems, ultimately to cause a wide array of water quality and user problems (Dunst *et al.* 1974). There are few countries that have escaped the problem of eutrophication – this includes South Africa, which has some of the most highly enriched surface waters in the world (Toerien 1974; Toerien *et al.* 1975; National Institute for Water Research (NIWR) 1985).

South Africa, through the initiatives and support of the Water Research Commission, carried out an extensive series of research projects on eutrophication between 1972 and 1985. The projects were aimed at assessing the status of surface water enrichment in the country, as well as its causes and consequences. They contributed to improving South Africa's eutrophication management capacity by providing information, creating institutional and human resource networks, as well as generating guidelines for its control (Walmsley and Butty 1980a, 1980b; NIWR 1985; Walmsley 1992). One of the most important outcomes was a decision to promulgate a 1 mg/ℓ P effluent standard for nutrient discharges in sensitive catchments (Taylor *et al.* 1984). This was widely expected to reduce general eutrophication problems in key catchment areas, but these expectations were not realized (Chutter 1989; Chutter and Roussouw 1991; Department of Water Affairs and Forestry 1999).

Since the 1980s there has been the general perception that water resource authorities in South Africa have regarded eutrophication as a problem that does not merit a high priority because of the low return for the high cost of nutrient control (at source, during effluent treatment, and in receiving systems). As a consequence the topic received little management attention during the 1990s in terms of policy development, monitoring, reporting, capacity building, or research.

Recently, South Africa has undertaken comprehensive and participative reviews of its national water resource and environmental management policies. These reviews resulted in the promulgation of the National Environmental Management Act (NEMA – Act 107 of 1998) and the National Water Act (NWA - Act 36 of 1998). Both Acts have introduced new perspectives to the way in which wastes and the natural environment should be managed in South Africa. Recognising that the topic of eutrophication should still be regarded as an important water quality issue, the Water Research Commission, requested Mzuri Consultants to carry out a scan project with the objective of assessing the situation and providing a framework which can be used to promote and guide research and capacity development in South Africa.

The project involved the following approach:

- An international scan of countries and organisations was undertaken to establish the most recent management and policy approaches to eutrophication, and the research that is in position to support these approaches;
- Making contact with some local stakeholders and specialists in order to establish their own concerns and opinions; and
- Preparation of a report that contains the findings of the scan and presents a framework as to how, and what research can assist with the management of eutrophication in South Africa.

This report contains the findings of these tasks and is intended to act as a discussion document for use by water resource practitioners for the purposes of:

- Understanding the general problem of eutrophication and its management through social, economic and technological approaches;
- Developing appropriate policy;
- Developing approaches to research and monitoring; and
- Developing relevant capacity to deal with the problem.

2. CONCEPTS OF EUTROPHICATION

2.1. Introduction

There is vast amount of published literature on the topic of eutrophication. This fact highlights its importance not only as a water resource management problem, but also as a scientific research and technology topic. It is not the intention of this section to undertake an exhaustive review of eutrophication, but rather to emphasise key aspects and concepts associated with the topic. Over the last 30 years there have been many seminal reviews and publications on eutrophication (e.g. Stewart and Rohlich 1967; Vollenweider 1968; Likens 1971; Vallentyne 1974; Dunst *et al.* 1974; Toerien 1974; Walmsley and Butty 1980; Ambio 1990; Klapper 1991; Rast and Thornton1996; EPA 1999; EEA 1999; Australian and New Zealand Environment and Conservation Council (ANZEC) 1999; United Kingdom Environmental Agency 1999; Canadian Department of Environment 2000). Readers who require further detail and background should consult these references.

2.2. Definition and Understanding of the Term " Eutrophication"

"Eutrophication" is a traditional ecological term used to describe the process by which a water body becomes enriched with plant nutrients. During this process the water body accumulates organic matter (both living and decaying) and progressively changes its character from that of a deep water body (lake) to that of a wetland and, ultimately, to that of a terrestrial system. Eutrophication is therefore a term that is primarily associated with the process of natural ageing of lakes. Under natural conditions this process takes place over tens of thousands of years. However, over the last 100 years, human influences have greatly accelerated the rate of enrichment, thereby shortening the lifespan of water bodies. There are two types of eutrophication:

- **The natural process** that is dependent on the geology and natural features of the catchment. It is not reversible and continues *ad infinitum*, albeit at a slow rate; and
- **The human-induced process** that is related to anthropogenic activities. This latter process is known as **"cultural eutrophication"** as it is associated with human activities (social and economic), and accelerates the rate of ageing of a water body. Cultural eutrophication is reversible.

Cultural eutrophication was first recognised as a problematic environmental process when scientists were able to associate problem conditions in water bodies to increased nutrient enrichment from human activities (Stewart and Rohlich 1967; Vollenweider 1968). The process of eutrophication also became associated with a wide array of aquatic resource problems (Dunst *et al.* 1974). This led to many definitions of the term and a rather confused understanding of what it meant. One of the most widely accepted definitions of eutrophication is that of the Organisation for Economic Cooperation and Development (OECD 1982) which describes the process as ***"... the nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, amongst which increased production of algae and aquatic macrophytes, deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses".***

Some parties see nutrient enrichment as having far wider implications than just water quality problems in aquatic ecosystems. This is because of the extent by which flows of anthropogenic nutrient-containing materials have impacted on continental air, terrestrial and aquatic systems. The issue is, therefore, perceived as being one of sustainable use of natural resources (material sources of nutrients), nutrient flow through ecosystems, and the multiple impacts on air, land and water (EEA 1999; Canadian Department of Environment 2000).

The terms "eutrophic", "oligotrophic", "mesotrophic" and "hypertrophic" are terms used to describe the state of enrichment of aquatic ecosystems (Nauman 1919; Rast and Thornton 1996). In this classification system:

- **Oligotrophic** means the presence of low levels of nutrients and no water quality problems;
- **Mesotrophic** means intermediate levels of nutrients, with emerging signs of water quality problems;
- **Eutrophic** means high levels of nutrients and an increased frequency of water quality problems; and
- **Hypertrophic** means excessive levels where plant production is governed by physical factors. Water quality problems are almost continuous.

2.3. Nutrients

The linkage between aquatic plant production, nutrients and human activities was first noted in the early part of this century (Nauman 1919; Thieneman 1925). However, it was not until after the 1960s that a clear scientific understanding was developed. Between the 1960s and 1980s, considerable limnological research was directed at identifying and quantifying the key nutrients in the eutrophication process (see Stewart and Rohlich 1967; Vollenweider 1968; Schindler 1974; Likens 1971; Vallentyne 1974; Dunst *et al.* 1974). South Africa also contributed to the development of the global understanding (e.g. Toerien 1974, 1977; Toerien *et al.* 1975; Walmsley and Butty 1980; National Institute for Water Research (NIWR) 1985). This early work contributed greatly to the understanding of nutrients and their impacts on the aquatic environment (Rast and Thornton1996; EPA 1999; EEA 1999). In general, for freshwater ecosystems, the following are some of the key principles concerning nutrients:

- A nutrient is a chemical compound or element that can be used directly by plant cells (algae and aquatic macrophytes) for growth. In the context of eutrophication, nutrients are mostly inorganic elements that are assimilated by plants and, in conjunction with the process of photosynthesis, are utilized to produce and accumulate organic material in aquatic ecosystems.
- Algae and aquatic macrophytes require about 20 different elements. However, the rate and extent of aquatic plant growth is dependent on the concentration and ratios of nutrients present in the water. Plant growth is generally limited by the concentration of that nutrient that is present in the least quantity relative to the growth needs of the plant. This is known as **the limiting nutrient concept** and is the basis of eutrophication management policy.
- The overall composition of aquatic plant tissue is $C_{106}\ H_{263}\ O_{110}\ \ N_{16}\ \ P$ yielding a C:N:P w:w:w (weight) ratio of 41:7:1 (C=Carbon atom; H=Hydrogen atom, O=Oxygen atom; N= Nitrogen atom; and P= Phosphorus atom). The ambient optimal N:P ratio (w:w) for algal growth in surface water is in the range of 8:1 to 12:1. Because of nutrient supply and demand in nature, it has been observed that phosphorus (P) and nitrogen (N) are the most frequent limiting nutrients in freshwater systems. Increases in the levels of either of these two nutrients in a water body will raise the risk (and frequency) of experiencing eutrophication problems. Management of N and P inputs to the aquatic environment is, therefore, the key to the eutrophication problem.
- The availability of C to plants is controlled by the calco-carbonate equilibrium in the water, and C limitation is normally restricted to short-term and transient circumstances (hourly) under conditions of high aquatic plant standing crop (populations).
- Other nutrients can be important, but usually only under special circumstances. Silicon is essential to diatoms and can determine the type of planktonic or epiphytic populations found in aquatic systems. Micronutrients such as Fe and Mo have been shown to be limiting in extremely pristine waters and some marine areas.

- Nitrogen occurs in surface waters in several forms (e.g. ammonium, nitrite, nitrate, urea, and nitrogen gas). All freshwater algae are able to assimilate the first four forms, but nitrogen gas can only be utilised by certain species of blue-green algae (cyanobacteria such as *Anabaena* species). The nitrogen cycle is extremely important in determining the availability of N (timing and quantity) in surface waters.
- Phosphorus occurs as orthophosphate, polyphosphates and organic phosphates both dissolved or bound to particulate material. Orthophosphate is generally considered to be the most immediately available form of P. However, mineralisation, sorption onto suspended material or sediment, desorption under aerobic conditions, luxury uptake by plants, and precipitation with calcium or iron, are all processes that play important roles in influencing the concentration of available P in fresh and marine waters.
- Biological growth and decay processes in aquatic ecosystems are important in determining the levels of available nutrients. Plants accumulate nutrients whilst bacteria mineralize them, but the processes occur at different rates. Real time observations of ambient concentrations can therefore lead to an incorrect understanding of the roles of nutrients such as C, N and P. It is, therefore, important to have a holistic ecosystem perspective of the situation. An eutrophic ecosystem is one where the potential concentration of nutrients is excessive even if instantaneous concentrations might be low.
- There has been, and still is, considerable debate about whether N or P is the more important nutrient. However, P is recognized as the fundamental cause of eutrophication (Chiaudani and Premazzi 1986; Carbiener 1992) because:
    - Better empirical relationships have been observed between algal growth and P concentrations in lakes and reservoirs.
    - P availability determines the influence of the other nutrients
    - Because of its chemical and biological properties P can be better managed and controlled through physical, chemical and biological means.
    - Nitrogen plays a secondary role, but can become important at a high level of eutrophication. In this case N-fixing cyanobacteria can cause nuisances much more significant than other types of alga (Korselman and Meuleman 1996).
    - It is recognized that the systematic elimination of P in terms of its availability in surface waters is the only practical way to combat eutrophication. Other modifying factors are mostly impractical to control.
- There are many modifying factors that influence the impacts of increased enrichment. Some of the main ones include:

  - The N:P ratio in the water which can have a great influence on the type of algae found in a water body, hence mitigating or aggravating the impacts on resource usage. The N:P ratio is not so important at high levels of nutrients when there are excesses of both N and P;
  - Geology and soils of the catchment which can contribute to high natural background levels of N and P from mineral sources;
  - Hydrology has an impact through the flushing or non-flushing of materials through aquatic ecosystems. Well- flushed systems can tolerate higher inputs of nutrients;
  - Timing in which nutrients are supplied to the aquatic system – the response of algae and aquatic macrophytes to increases in available nutrients is not always the same and can vary with time;
  - Sediments of aquatic ecosystems are well-known for releasing nutrients into the water column hence exacerbating or prolonging the eutrophication problem. The rates of release for N and P from sediments differ;
  - Seasonality and temperature regimes that affect stratification and algal production patterns;
  - Inorganic turbidity has an influence through its impact in reducing the amount of available light for plant production. Turbid systems will tolerate higher levels of nutrients;
  - Lake morphology influences impacts through both depth and shape. Deep lakes can tolerate higher inputs of nutrients; and
  - General catchment characteristics (e.g. land-use, vegetation cover, presence of wetlands, reservoirs and other systems that retain or modify nutrient transport over the landscape) will modify the impacts of increased nutrient loading.

- There has been much research effort aimed at quantifying the in-lake P concentrations and loadings, above which the risk of eutrophication problems increases (Rast and Thornton 1996; EPA 1999). These have mostly provided log-log relationships that are insufficiently sensitive to allow for reliable or realistic management decisions (Thornton and Walmsley 1982). Nevertheless, these relationships suffice to demonstrate that P is the dominant factor influencing the eutrophication status of the majority of water bodies;
- It is important to consider the question of what constitutes an excess of nutrients? The EEA (1999) defines this as being "a nutrient load supplied in such a quantity as to result in:

- Direct effects (e.g. toxic effects) which can be intermediate or predictable (due to nutrient accumulation) and which can be observed directly in the ecosystem or in the river/water uses; and
- An increased production of biomass, which exceeds the aerobic mineralisation capacity of the ecosystem.

- Excess nutrients should always be assessed against what is known about the reference or background condition – notably the level of nutrients that is supplied to the aquatic ecosystem by non-anthropogenic processes (geology, soils, vegetation etc.);
- Workers have reported that eutrophication-related problems in temperate zone aquatic systems begin to increase at ambient total P concentrations exceeding 0.035 mg P/l (see Table 2.1). The value is higher for warm water systems – of the order of 0.070 mg P/l (Rast and Thornton 1996). The associated N concentration would be of the order of 0.34 – 0.70 mg N/l respectively. It is accepted that these represent nutrient threshold levels beyond which there will be a corresponding increase in the risk and intensity of plant-related water quality problems. The OECD (1982) has published guidelines that relate P and chlorophyll ***a*** concentrations to trophic condition (Table 2.1). These values are considered to be fairly universal for temperate zone systems;

Table 2.1: OECD (1982) criteria for assessing the trophic status of water bodies

Indicator	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Total Phosphorus					
Annual average in µg/l	<4	4-10	10-35	35-100	>100
Chlorophyll ***a***					
Annual average in µg/l	<1	<2.5	2.5-8	8-25	>25
Annual Maximum	<2.5	<8	8-25	25-75	>75

2.4 Sources and Flows of Nutrients

An overall perspective of the eutrophication process can best be understood through a systems linkage approach to nutrients, their sources and their pathways to the aquatic environment (Figure 2.1). Knowledge of both the N and P cycles is also important as these cycles influence the availability of these two nutrients. The main driving force to the eutrophication problem is human population growth and associated economic activities. Human activities make use of numerous

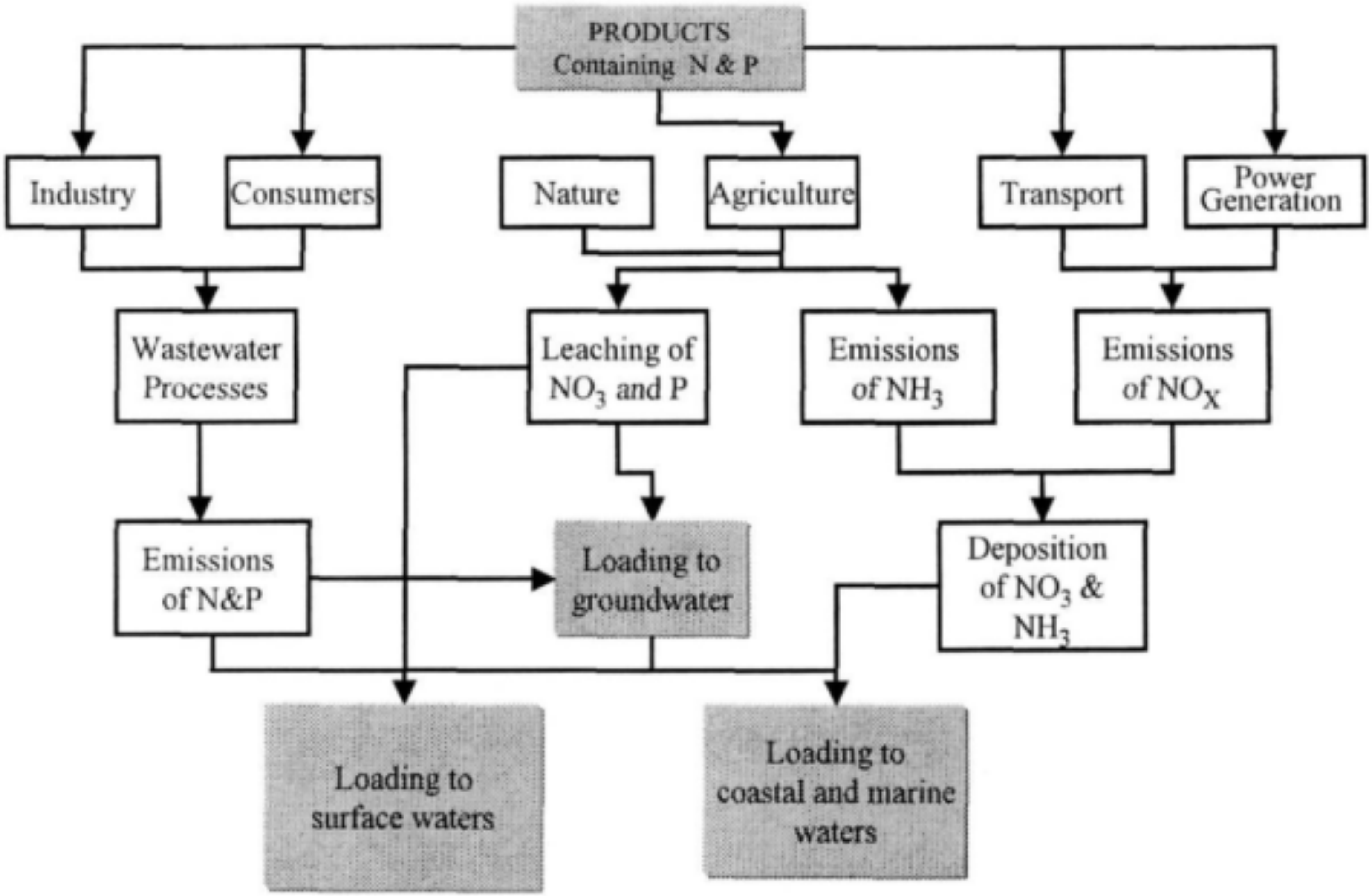

Figure 2.1: Schematic representation of the eutrophication process to illustrate the flow of N and P from various sources into aquatic ecosystems (adapted from EEA 1999).

products and resources (containing bound N and P), ultimately converting them into available N and P that are released into the aquatic environment through various pathways.

There are numerous products that act as primary sources of N and P. Examples of these include:

- Detergents which have a high P content and are used for domestic and industrial cleaning;
- Foodstuffs (e.g. meat, cereals, milk etc.) that are part of the everyday consumer economy all contain N and P which is ultimately discharged into the environment via sanitation and sewage treatment systems;
- Fertilisers that contain high levels of N and P (and other plant nutrients) are applied to agricultural land to stimulate crop productivity. Most fertilizer applications are often in excess of actual requirement and are an important source of nutrients;
- Fossil and wood fuels such as coal, oil and wood that are used for transport and power generation contribute to atmospheric discharges of nitrogen oxides that are then deposited on to land and water surfaces; and
- Materials such as fishmeal, hay and grass (and supplements) that are supplied to animals in feedlots all have a significant N and P content. The animals consume the material and their wastes, which are high in ammonia and phosphate, are then discharged into the aquatic environment. Ammonia is also emitted into the atmosphere and reaches the aquatic environment through atmospheric deposition.

There are two main ways in which nutrients are introduced to the aquatic environment. In the eutrophication context these can be classified as **point** and **diffuse** (non-point) sources.

A point source is usually a location of high nutrient concentration (e.g. a factory, domestic wastewater plant, an animal feedlot) where some form of effluent is discharged (via a pipe) directly into a receiving aquatic system (river, reservoir, lake, sea).

A diffuse source is a location with multiple nutrient sources that are spread over a much wider area and nutrients enter the aquatic environment through leaching and atmospheric deposition processes (e.g. an agricultural field, atmospheric depositions, a township or an urban area). For diffuse sources the nutrients are transported over the landscape and come into contact with soils and vegetation before entering the aquatic environment.

It is generally accepted that, because of containment volumes and concentration characteristics, nutrient management and control is much more easily implemented at point sources than diffuse sources (Dunst *et al.* 1974).

During their transport from primary sources to the receiving aquatic system, all nutrients undergo transformations that are associated with cycles (see P and N cycles) that change their concentration, chemical form and availability. It is well-documented that not all of the potential supply of N and P eventually ends up in the receiving aquatic environment (e.g. Likens 1972). The longer the distance (and time) between the source (e.g. factory, field, feedlot, township) and the water body of concern, the lower will be the amount of nutrients that contribute to eutrophication problems.

2.5. Eutrophication problems

The problems associated with excessive eutrophication are numerous and they may be both long- and short-term. These include, amongst others (Toerien 1974; Dunst *et al.* 1974):

- Increased occurrence and intensity of nuisance algal blooms;
- An increasing dominance by blue-green algae;
- Increased occurrence of toxic algae;
- Clogging of reticulation systems by filamentous benthic algae;
- Increased occurrence of floating and rooted aquatic macrophytes;
- Increased occurrence of taste and odour problems in drinking water;
- Increased occurrence of deoxygenation in bottom waters with associated chemical effects (hydrogen sulphide and elevated levels of heavy metals);
- Increased fish and invertebrate mortality;
- Changes to ecological community structure and loss of biodiversity;
- Increased water treatment costs through filter clogging in water treatment works;
- Increased interference in recreation activities (boating, fishing, swimming);
- Increased occurrence of human health problems (gastroenteritis, skin complaints);
- Loss of property values
- Interference with irrigation and livestock agriculture (e.g. clogging of irrigation equipment/canals, mortality of stock);
- Undesirable aesthetic conditions (e.g. turbidity, foam, discolouration, odours);

Most of the above problems are socio-economic in their impact as they have direct effects on society through impairment to the use of aquatic resources and the costs incurred to make such resources usable.

The ecological impacts of eutrophication are reflected through influence on natural biological communities. The ecological components of the natural environment provide one of the most effective treatment systems for eutrophication control, a feature known as **natural assimilative capacity** (see Quibell *et al.* 1997). Assimilative capacity is dependent on the presence of appropriate biodiversity and physical form in the landscape over which nutrients are transported (e.g. plant communities, ecosystems such as wetlands, vegetation, soils, bacteria, zooplankton, fish etc.). Any activity that reduces this biodiversity can result in a reduction of the assimilative capacity. Housing and industrial developments, land-use changes, agricultural activity, waste management malpractices, and general pollutant overloading, are all activities that diminish the capacity of the natural environment to purify eutrophication wastes. The loss in general catchment assimilative capacity is one of the hidden costs (externalities) that decision-makers fail to take into account when setting policy and practice on eutrophication control.

Experience with these problems has also shown that eutrophication problems can be solved through technical interventions, but it is largely social, economic and political barriers that prevent the implementation of interventions (McCann 1999). It is extremely dependent on the implementation of the "polluter pays principle" as upstream sources of nutrients will affect downstream users.

The eutrophication problem is essentially a human-perception problem as it is site-specific. It is related to how a community perceives the value of a specific water resource and the effort and price it is willing, or able, to pay in order to solve the problem (Rast and Thornton 1996). Thus two communities with the same level of eutrophication problems in their water supplies are unlikely to react in the same way to the problems and their solutions. The response of each is likely to be based on the socio-economic standing of the community and the willingness to pay for waste management and rehabilitation activities. It is also highly dependent on the relative strength of political structures and the channels of communication that are in operation.

2.6 Management strategies and options

An overall perspective of the eutrophication problem and the numerous options for its control can best be understood through a systems and linkage approach to nutrients, their sources and pathways to the aquatic environment (see Figure 2.1 on page 10). The real driving force to the eutrophication problem is population growth and increased economic activities that convert specific products into available N and P. These nutrients then, via many sources and pathways find their way into the aquatic environment.

Technical interventions to controlling and minimizing the eutrophication problem were well discussed and documented in the 1970s. They focus within the themes of waste minimization, source control and impact control (Dunst *et al* 1974: EEA 1999). These include:

- Product modification such that the use of source materials containing high levels of N and P are either minimised or are not used at all by key social and economic activities (e.g. replacement of phosphate-based detergents in the domestic and industrial cleaning industries);
- Controlling the output of nutrients from point sources by setting standards for N and P emissions and applying specific wastewater or air emission control technologies. This applies particularly to removal of N and P from wastewaters, and there are numerous technologies available for their removal from wastewaters of all types (see Brett *et al* 1997);
- Limiting the output of nutrients from diffuse sources. This approach generally requires changes to practices and procedures of land-use management (e.g. farming practices and fertilizer application);
- Applying techniques that restrict and prevent the flow of nutrients over the landscape and through river systems (e.g. creation of buffer zones, wetlands, detention ponds etc.)
- Applying in-stream removal techniques (nutrient removal treatment at the inflow to reservoirs; nutrient diversion);
- Numerous management techniques within the receiving waters that reduce the availability of nutrients. These include amongst others:
    - Nutrient inactivation
    - Selective discharges
    - Aeration
    - Lake bottom sealing
    - Dredging of sediments

- Food chain manipulation with the objective of managing the ecosystem to yield valuable and harvestable crops (e.g. aquaculture), or the addition of specific organisms;
- Controlling unwanted organisms by physical removal or habitat manipulation; and
- Use of chemicals such as herbicides and algicides to control nuisance plant growths.

Of the above options it is generally agreed that an approach that minimizes nutrients at source is the best as it is aimed at the root of the problem and provides a long-term solution (Dunst *et al* 1974). The other options are short-term and aimed at controlling the effects of the problem. Control of nutrient emissions from point sources (factories and waste water treatment plants) is considered to be the best approach, but does require a long-term perspective (even decades) before achievement of objectives. Case studies have demonstrated that the best approach is one in which a suite of interventions (combinations of the above) are carried out in order to achieve both long-term and short-term improvement to water quality (Dunst *et al.* 1974; EEA 1999; EPA 1999).

Many of the developed countries have set measurable targets of nutrient reduction, based on receiving water quality objectives (see section 3). National, and catchment-related, policies and programmes are then based on the achievement of these targets. Success stories have been achieved in Europe and North America where control programmes have been in place for many years (EEA 1999; Canadian Department of Environment 2000).

2.7 Summary points

1. Eutrophication is a process by which aquatic ecosystems become, over time, progressively enriched with plant nutrients. The enrichment results in an increased production of organic material by aquatic plants (algae and weeds). The process is therefore also associated with the appearance of nuisance plant growths and water resource impairment problems. Eutrophication, caused by enrichment from anthropogenic activities (cultural eutrophication) is a major global water resource problem.

2. Nutrients originate from a variety of sources, but the most significant are within materials (consumer commodities, foodstuffs, fuels, detergents, fertilizers, biomass etc.) that are generated or used for major socio-economic activities such as municipal waste management, transport, agriculture and energy generation. Phosphorus and nitrogen have been identified as the key nutrients in the eutrophication process.

3. Excessive eutrophication is a pollution problem that requires the application of sound waste management principles. The main strategy is for nutrient reduction (primarily phosphorus and nitrogen) via waste minimization and source control, the extent of which is dependent on receiving environment objectives. The involvement of stakeholders and water users in the setting of environmental objectives, and the funding of interventions, is paramount. There are well-established technical interventions for solving eutrophication problems at almost every scale.

4. The relationship between nutrient inputs and their impacts is extremely complex as there are many factors that can modify (enhance or diminish) the responses of plants to nutrient enrichment. Nevertheless scientists have been able to provide indications of the phosphorus and nitrogen levels above which impairment problems can be expected. In general, the most severe eutrophication problems are experienced in areas where the scale of anthropogenic nutrient inputs far exceeds the capacity of the natural environment to assimilate the waste.

3. AN INTERNATIONAL PERSPECTIVE

3.1 Introduction

Since the 1960s, most of the world's developed countries have regarded eutrophication as a priority water quality issue. This is particularly the case for the OECD countries, where there has been a continual monitoring of eutrophication and its impacts (OECD 1983; Morse *et al* 1993; Rast and Thornton 1996; EEA 1999). The problem has also received attention in highly populated countries of South-East Asia and South America, but less so in Africa.

For this project, a scan was made of available literature through library searches, internet web-sites, and personal contacts. The countries/organizations contacted included:

- United States of America
- European Union Countries
    - European Environment Agency
    - United Kingdom
    - Denmark
    - Sweden
- Australia
- Canada
- Malaysia
- Thailand
- Southern African Development Commission (SADC) countries (excluding South Africa):
    - Swaziland
    - Namibia
    - Zimbabwe
    - Botswana
    - Mozambique
    - Lesotho
    - Zambia
    - Tanzania
    - Mauritius
    - Seychelles

In each case the countries and individuals were requested to provide an indication of:

- Any policies on eutrophication at national or state level;
- Any published material on the national research programme;
- Any funding allocations to projects by the national funding agency;
- Any progress that you have made over the last 5 years (recent annual reports); and
- An indication of the human resources that have been applied to the problem.

Unfortunately not all countries, or the individuals approached, were able to provide the required information. This overview, therefore, focuses on those countries from which replies were received. From the available information, a general conclusion can be made that eutrophication is a major societal concern in OECD countries, where it forms a priority part of water resource policy and management practice. This is not as apparent in South American, African and Asian countries, but does not imply that countries in these areas do not experience eutrophication problems or are not acting to reduce them.

3.2. United States of America (USA)

3.2.1 Extent of the problem

Most of the knowledge on concepts and techniques for eutrophication management have emerged from the USA. This is because the problem was identified as a serious threat in the 1960s and appropriate knowledge-generating research and monitoring programmes were put in place (see Stewart and Rohlich 1967; US National Academy of Sciences 1969; Likens 1972; Dunst *et al.* 1974; Rast and Thornton 1996; EPA 1999). Despite this, eutrophication still remains a widespread problem throughout the USA and ranks as one of the top causes of water resource impairment (EPA 1999). In 1996 the EPA reported that 40 percent of impaired rivers, 51 percent of lakes, and 57 percent of estuaries were impaired by bacteria and nutrients (EPA 1996). There are few States in the USA that do not experience severe eutrophication problems in their major rivers and water supplies.

3.2.2 Policies and approach to eutrophication management

Water resource management policy in the USA is reflected in the Clean Water Act (CWA) that is a 1977 amendment to the Federal Water Pollution Control Act of 1972 (http://www.epa.gov). The law gives the EPA the authority to set effluent standards and makes it unlawful to discharge any pollutant from a point source into surface waters unless a permit is obtained.

Eutrophication is recognised as a national water resource problem and, accordingly, the USA has official policies and programmes in place that reflect this high priority. The EPA is the main federal agency that facilitates the development of policy and facilitates the implementation of the Act.

The USA approach to eutrophication is based on two principles. Firstly, that total integrated watershed (catchment) management is the basis of sound water resource management and eutrophication is considered to be a problem that is only part of watershed management. Secondly, nutrient enrichment from cultural practices is a problem that requires specific policies and management actions.

This approach is reflected by recently-initiated actions and programmes. In 1998 the White House requested federal agencies to develop and implement a comprehensive plan that would help revitalize the nation's commitment to water resources. The result has been the ongoing Clean Water Action Plan (http://cleanwater.gov/news). This initiative is intended to provide cleaner water by strengthening public health protections, targeting watershed protection efforts in high priority areas, and providing communities with new resources to control polluted runoff and enhance natural resource stewardship. Included within this initiative are specific eutrophication actions that promote:

- The monitoring of water resources for changes in eutrophication status;
- The setting of nutrient criteria in receiving waters that relate to the maintenance of natural conditions and the avoidance of nutrient enrichment. Established criteria most commonly pertain to P concentration in lakes. Nitrogen criteria are not eutrophication-related and are based on the toxic effects of ammonia and nitrate; and
- The setting of standards that are incorporated into State or Federal law. The water quality standards are based on three different perspectives: criteria should be scientifically based; uses involving social, economic and political concerns should be included; and, anti-degradation considerations protecting downstream receiving waters should be included.

At the minimum, uses include recreation in and out of the water, and the propagation of fish and wildlife. Recreation and wildlife, therefore, form the priority reasons for implementing eutrophication control.

The EPA believes that the USA strategy for reducing cultural eutrophication should be based on five key elements. These are (http://www.epa.gov/ost/standards/guidance/lakenutr.pdf):

- Nutrient criteria that will be established on a regional basis and be appropriate to each water body type. This is because criteria cannot be established as a single set of national numbers or values as there is too much natural variation from one part of the country to another. The EPA has defined 14 regions. Furthermore, the expression of nutrient enrichment and its measurement varies from one water body type to another (e.g. streams, wetlands, estuaries, lakes, reservoirs, coastal waters);
- The preparation of guidance methodology for the development of criteria based on water body type and regions;
- The setting up of a country-wide management network. The EPA has initiated a countrywide system that will develop nutrient criteria for the country. It consists of a system of EPA regional technical and financial support operations each led by a Nutrient Co-ordinator (a specialist responsible for providing guidance to the States and Tribes in the specific region). This national programme will be guided and supported by a team of inter and intra-agency specialists from EPA headquarters;
- The development of nutrient criteria for use in decision-making. States and Tribes will develop eco-regional nutrient criteria values for water body types that can be used as the basis for the setting of water quality standards, the issuing of discharge permits, the assessment of total daily maximum loads to water bodies, and as decision-making benchmarks for management planning and assessment; and
- The monitoring and evaluation of the effectiveness of nutrient management programmes implemented on the basis of the nutrient criteria.

The Clean Water Action Programme has nine federal agencies (the Department of Agriculture, Environmental Protection Agency, Department of the Interior, Department of Defense (including U.S. Army Corps of Engineers), Department of Commerce, Tennessee Valley Authority, Department of Energy, Department of Transportation, and Department of Justice) working with tribal, state, and local partners to implement 111 key actions in the Action Plan and build a new framework for watershed protection.

The main actions during 1999 included:

- Twelve regional watershed round-tables to support and help develop community-based watershed efforts across the country.

- The development of numeric criteria for nutrients (i.e., nitrogen and phosphorus).

3.2.3 Research Trends

Rast and Thornton (1996) have outlined the main lines of investigation that are currently being pursued within the USA on the topic of eutrophication. These include:

- The climatic and regional differences between receiving waters based on their response to nutrient enrichment – and the development of nutrient criteria for these systems;
- Public perceptions of eutrophication;
- Refinement of predictive models;
- Development of control measures; and
- Development of alternative eutrophication indicators or sets of eutrophication indicators.

3.3. Canada

3.3.1 Extent of the problem

Eutrophication is considered to be a high priority water quality problem in Canada and, over the years, considerable effort has been spent in assessing the problem, its causes and consequences. Some seminal eutrophication studies during the 1970s were conducted by Canadian scientists (e.g. Dillon and Rigler 1974 ; Schindler 1974).

One of the most classic cases of eutrophication has been that of the Great Lakes where in the 1960s cultural eutrophication, from both Canada and the United States, was considered to be a international strategic threat (Burns 1976). This resulted in a long-term programme to assess and remediate the aquatic environment of the Great Lakes, an action which has resulted in a substantial reduction in P loading and eutrophication problems in the lakes (Lesht *et al.* 1991).

In 1994, during a review of the country's Environmental Protection Act, a Parliamentary Committee on Sustainable Development and the Environment expressed concern about nutrients and their impacts on the Canadian environment. A subsequent overview by a team of senior government scientists (still undergoing peer review and discussion - Chambers, personal communication [1]) has provisionally concluded that *"nutrients are causing problems in Canadian ecosystems and affecting the quality of life of many Canadians"*. The scientists outline the problems as including:

- Accelerated eutrophication of certain rivers and lakes, resulting in loss of habitat, changes in biodiversity and loss of recreational potential;
- Increased frequency and spatial extent to which drinking water guidelines for nitrate have been exceeded in ground waters across the country;
- Fish kills in South-western Ontario due to ammonia toxicity;
- Decline in amphibians in Southern Ontario due to long-term exposure to elevated nitrate;
- Elevated risks to human health through the frequency and spatial extent of toxic algal blooms in lakes and coastal waters;
- Acidification of soils in Southern Ontario and Quebec and resultant incipient N saturation in some forested watersheds;
- Increased carbon production in Canada's forests due to N deposition;
- Increased concentrations of NO_X in the atmosphere that contribute to photochemical smog in certain Canadian cities;
- Quality of life concerns through water use impairments to water supplies (e.g. visual, odours and tastes); and
- Increased economic burdens as a result of the need for treatment, monitoring and remediation of contaminated water.

Nutrient release into the environment therefore has wider implications than just eutrophication. The problem of eutrophication in Canada is ubiquitous in aquatic systems throughout the country's provinces and territories where there are cities and/or agricultural development. It is estimated that at least 63% of the P and 30% of the N entering Canadian surface fresh waters from human activity is derived from municipal sewage and industrial sources. Agricultural activities contribute significant amounts of N to the environment (atmosphere, surface waters, marine waters and general landscape).

The scientists emphasise that current Canadian nutrient control measures should not be relaxed and that the best and most advanced science should be integrated into practical solutions to maintain and improve the quality of air, water and soil environments.

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[1] Dr Patricia Chambers, Chairperson of Government Task Group, National Water Research Institute, Department of the Environment, Saskatoon, Saskatchewan, Canada

3.3.2 Policies and approach to eutrophication management

Canada has a well-developed approach to the protection and management of its aquatic environment (http://www.cciw.ca). The management of surface water resources is considered part of integrated environmental management and falls under the jurisdiction of the Department of Environment (http://www.ec.gc.ca). The system is characterised by the following features:

- There is a federal Environmental Protection Act (1988) that legislates for management of the environment in an integrated way. Environmental management enjoys a high political priority and there are regular five-yearly reviews of the Act by a Parliamentary Committee on Sustainable Development and the Environment. The problem of nutrient release into the environment has long-been an item on the political agenda. In both the 1988 and 1994 reviews the Canadian government was called on to comprehensively assess whether the problem of nutrients was being adequately dealt with;
- *The Environmental Protection Act (1988) is the only federal act to directly address* environmental concerns related to nutrients. It gives the federal government the authority to regulate nutrients that can cause excessive growth of algae and aquatic weeds, as well as to deal with toxic substances, hazardous waste and air pollution. Phosphorus in laundry detergents is the only nutrient source currently regulated and laundry detergents may not contain P in concentrations greater than 2.2% w/w;
- There is a bilateral international Canada-United States Great Lakes Water Quality Agreement (1972) that is aimed at rehabilitating these important water bodies. It commits both countries to remove P from detergents and effluents, as well as to monitor the Great Lakes for trends and emerging water quality issues;
- The country has developed Water Quality Guidelines (1987) and Drinking Water Guidelines (1996) that are nationally applicable, scientifically based tools for water resource management. Most provinces in Canada have developed their own water quality guidelines for various nutrients. The provinces and territories all have varying degrees of nutrient legislation, regulations, objectives, best management practices and other measures. Some of these actions are fairly stringent and well regulated by the provincial governments. They have all been developed to serve the values, interests and specific characteristics of the respective provinces;

- There appears to be a relatively well-operated system of federal, provincial and territorial institutions that support environmental protection through the provision of support in the form of research, monitoring, information and professional advice; and
- Federal, Provincial, Territorial and local community organizations have all responded to the eutrophication problem by instituting a variety of nutrient control activities (e.g. legally enforceable acts, promotion of best management practice guidelines, partnership initiatives. volunteer rehabilitation programmes).

3.3.3 Research Trends

The Canadian task group has acknowledged that its assessment of the impacts of nutrients has been constrained by data limitations of two categories: insufficient data on emissions and ambient conditions, and insufficient knowledge as to the effects of nutrients to ecosystem and human health. The areas where information is required include:

- Industrial loading to surface waters;
- Municipal water treatment loading to surface waters;
- Agricultural loading to surface and ground waters;
- Atmospheric deposition of P;
- Ground water quality, particularly ammonia and P;
- Fish kills from spills of nutrient-related compounds;
- The role of nutrients in inducing cyanobacterial blooms and toxin production;
- The role of nutrients in causing taste and odour problems;
- Interactions of nutrients with organic contaminants and their effects on aquatic food webs;
- The effects of sewage and industrial wastewater plumes on aquatic life during ice cover;
- The fate and transport of nutrients within different ecosystems (wetlands, coastal waters, forests, rivers and lakes);
- Effects of long-term loading on aquatic and terrestrial ecosystems (including water and sediment/soil) and food webs;
- Cumulative effects on the aquatic environment from the combination of several nutrient sources all operating within a region;
- The relationship between nutrient concentrations and aquatic plant biomass, particularly for streams and coastal waters. In addition, the level of aquatic plant biomass that begins to impair beneficial uses of streams for the preservation of aesthetic/recreation and the protection of aquatic life;

- The contribution of nutrients to other environmental problems (e.g. urban smog);
- The effects of using alternative products that contain other chemicals;
- The effects of nutrient enrichment in stimulating invasive alien organisms; and
- The potential impacts of increased livestock production.

One important facet of all the above research and information requirements is a limitation caused by the absence of a central storage system for eutrophication data and information in Canada (Chambers, personal communication[1]). Knowledge and information transfer through synthesis and analysis of existing information is, therefore, constrained by the accessibility to information.

3.4. Australia

3.4.1 Extent of the Problem

In a recent Australian State of the Environment Report, nutrient enrichment is reported as being a threat and one of the major water quality problems facing Australia (Australian State of the Environment Advisory Council (ASEC) 1996; http://www.environment.gov.au/). It is particularly severe in inland waters of the more highly populated South-East portion of the country (in the states of New South Wales (NSW) and Victoria) where algal blooms are prevalent in many reservoirs and river systems. Several estuaries and coastal areas also exhibit problems.

All of the common symptoms associated with eutrophication have been observed in numerous Australian inland, estuarine and coastal waters. These include: decreased clarity of water, decreased diversity of aquatic plant and animal life, de-oxygenation of bottom waters, algal blooms and associated toxicity and taste and odour problems. Of special interest is the fact that in 1991 the Darling River experienced the world's largest toxic algal bloom along a 1000 km stretch.

Nutrient inputs originate from both point and non-point sources. Although a national budget is not available, loading figures for several catchment areas, where eutrophication problems occur, reveal that diffuse sources are highly significant (loads as high as 90% of P loading – ASEC 1996). The extensive use of super-phosphate fertiliser has been singled out as the major source of P in Australian inland waters. Soils in many rural areas have been shown to have a high P content, thereby providing a long-term source of P to key river systems such as the Murray-Darling. The

[1] Dr Patricia Chambers, Chairperson of Government Task Group, National Water Research Institute, Department of the Environment, Saskatoon, Saskatchewan, Canada

loading of P to the Murray-Darling has been shown to dependent on hydrological conditions, as during wet years diffuse sources contribute much higher P loads.

3.4.2 *Policy and Approach*

Water resource and land management has a relatively high profile in Australia (http://www.erin.gov.au). There are both federal (commonwealth) and State laws that deal with water resources and the environment (e.g. The Water Resources Act (1974) and the Environmental Protection and Biodiversity Conservation Act (1999)). At both the federal and State levels, water resources are strongly aligned with land and agriculture. Federal water resource policy is handled by the Department of Agriculture, Fisheries and Forestry. Each of the States or Territories have equivalent government departments that deal with legislation and regulation of land and water resources.

Over the years the country has launched numerous reform initiatives that deal with achieving sustainable development of water resources (http:/www.environment.gov.au/psg/igu/csd99). These include:

- An integrated catchment management approach;
- Water pricing that reflects costs of supply and servicing (including environmental costs);
- Institutional arrangements that are clearly defined;
- Measures to address structural and social impacts of reform;
- Community involvement in the water reform process;
- The development of natural resource management policies and programmes such as:
    - Decade of Landcare Plan;
    - National Landcare Programme;
    - Murray-Darling Basin Initiative;
    - National Water Quality Management Strategy;
    - Monitoring River Health;
    - National Waterwatch; and
    - Research and Development activities such as the Cooperative Research Centres.

Eutrophication was not considered a major problem until the 1991 River Darling algal bloom. This event led to a complete change in the Australian water resource management's perceptions and attitude towards eutrophication and its management. The last decade has, therefore, seen an escalation in activities aimed at understanding and managing eutrophication in Australia (ASEC 1996). These have included:

- Nutrient management strategies;
- Algal management strategies;
- A senate enquiry into toxic algal blooms;
- Major research funding initiatives; and
- Community education programmes.

Most of the Australian States have developed and implemented policies targeted at both diffuse and point sources of phosphorus. These have included better farming practices to ameliorate nutrient losses to streams and guidelines for the use of buffer strips and other techniques for sediment and nutrient interception. Also included have been options for improved sewage treatment, P precipitation, off-river disposal and effluent re-use (http:/www.dwlc.nsw.gov.au).

Community-based nutrient management strategies have been developed and implemented through catchment management plans. Such plans include the upgrading of sewage treatment plants and treatment to reduce point sources, and a review of stream-flow management options to reduce the impact and likelihood of algal bloom development. Community education in Australia is considered to be an important part of eutrophication control because of both financing and actions required from communities. These communities need to both understand and participate in the long-term management of nutrient-reduction activities (e.g costly sewage treatment, product changes, rehabilitation actions, best agricultural practices).

NSW and the Murray Darling Basin Commission (MDBC) have had algal management strategies in place for the last five years and Victoria has had a Nutrient Management Strategy. These strategies include: nutrient reduction from both point and diffuse sources, as well as flow management techniques to control stratification in weir-pools and river pools.

A recent initiative, aimed at introducing and implementing a National Water Quality Management Strategy, is almost complete (Australian and New Zealand Environment and Conservation Council/ Agriculture and Resource Management Council of Australia and New Zealand 1999). In this strategy eutrophication management is integrated into a holistic approach that:

- Identifies the environmental values that are to be protected in a particular aquatic system. These values are based on particular values or uses of the aquatic resource. Stakeholders are implicitly involved in this process;
- Identifies the management goals for the system and then selects relevant water quality guidelines for measuring performance. Water quality management objectives are then set and these must be met;
- Develops performance criteria to evaluate level of management compliance;
- Develops monitoring programmes that focus on the water quality objectives; and
- Initiates appropriate management responses where objectives are not being met.

The strategy has proposed that 6 ecosystem types are considered as each require different approaches (flowing waters - upland and lowland, standing waters – reservoirs/lakes and wetlands, estuaries, coastal and marine waters). Specific indicators should be selected to assess the condition of each of these ecosystem types. The strategy recognises nutrients as an issue and has suggested appropriate indicators for assessment. This includes both concentrations and loads. Interim trigger levels for assessing possible risks and adverse effects have been proposed. These differ for the six respective ecosystems that have different sensitivities. Management approaches also take into account the current condition of specific aquatic systems and the socio-political setting.

3.4.3 Research

Research has formed a strong part of the Australian approach to managing the eutrophication problem. At an early stage, the MDBC identified the need for research and development into the causes of algal blooms. They co-operated with the Land and Water Resources Research and Development Corporation (LWRRDC) to initiate and support a National Eutrophication Management Programme (NEMP) that has been ongoing since 1995. The individual State strategies did not call for any specific research and development, but the results of the NEMP have been nationally recognized and utilised. There are currently approximately 20 projects underway involving collaboration between numerous institutions (government, communities, CSIRO, Universities, etc).

The NEMP identified six priority areas. These included:

- A - Bioavailability of P, N and other nutrients;
- B - Sources and transport of nutrients in catchments;

- C - Management of sediment nutrient sources;
- D - Effects of episodic events on aquatic ecosystem ecology;
- E - Factors leading to the initiation and development of blooms; and
- F - Evaluation of effectiveness of actions to manage nutrients.

The Program (1995-2000) has addressed these priorities rather unevenly with most (69%) of resources for research being committed to Priorities B and E and approximately 31% to Priority A and C. Although a considerable effort was made to develop projects in the area of Priority D, this was unsuccessful. Few proposals were forthcoming in the area of Priority F and no attempt was made to fund research in that area (Richard Davis, personal; communication[2]).

The NEMP has made an important and useful contribution to water resource management knowledge since its commencement in August 1995. Examples of various results from the Program to date include:

- Phosphorus can travel through subsoil pathways in a wide range of east Australian soils, thereby bypassing surface interception measures. This has major local management implications;
- Nitrogen is equally important to phosphorus in controlling algal growth in the Murray Darling Basin, and possibly elsewhere;
- Light, and not nutrients, is commonly the factor that controls algal growth in inland rivers. This has major implications for current phosphorous control strategies; and
- The bioavailable fraction of phosphorus is roughly equal from dryland, irrigation and sewage treatment plant sources in the Goulburn River. It had been hypothesised that phosphorus from sewage treatment plants was more available to algae than phosphorus from dryland sources.

The NEMP has also included a focused catchment approach that has examined selected systems and aimed at producing information that is transferable to other catchments. A secondary objective was to provide information for improved management within the "focused" catchment. One of the key potential benefits from the focused catchment approach is to engender ownership of the research and, therefore, the research findings to the decision makers in the catchment.

[2] Richard Davis, National Coordinator of NEMP, CSIRO, Canberra, Australia

Although the 1995-2000 NEMP comes to an end during 2000, it is more than likely that there will be a second phase that builds on the capacity and knowledge of the first phase.

3.5 Europe

3.5.1 Extent of the Problem

There is evidence to indicate that eutrophication is widespread throughout the European community (EC), and excessive algal growth poses problems in many areas (EEA 1999; SCOPE 1999 – see Table 3.1).

Table 3.1: Eutrophication in the European Community (Scientific Committee on Phosphates in Europe (SCOPE) 1999).

Country	Extent	Key areas affected
Austria	Low	Some localized eutrophication
Belgium	High	Widespread eutrophication in rivers, canals, lakes and coastal waters
Denmark	High	Most inland waters, North Sea, Kattegat, Baltic
Finland	Low	Some localized eutrophication
France	Low	Localised to particular river basins: Loire, Meise, Saone,
Germany	High	Serious eutrophication in many inland waters, particularly in Bavaria, Rhine, North Sea and Baltic
Greece	Medium	Highly localized problems
Ireland	Medium	Threat to inland waters but not coastal
Italy	High	Most lakes and reservoirs. R Arno Tevere, Po, and Adriatic Sea
Luxembourg	Medium	Significant eutrophication
Netherlands	High	Widespread problems in all inland waters
Portugal	Low	Little evidence
Spain	Medium	Large number of inland water affected
Sweden	Medium	Eutrophication localized in the South
United Kingdom	Medium	Lough Neagh, Eastern England

The status of nutrient enrichment in European countries has recently been documented in a special report by the EEA (1999). This report, based on monitoring information provided by member countries, indicates that for the period 1992-1996:

- Apart from rivers in the Nordic countries (where 70% of stations had concentrations less than 0.3 mg N /l) 68% of all stations in Europe had annual average NO_3 concentrations exceeding 1mg N/l. Concentrations exceeding 20 mg N /l were found in countries of the northern part of Western Europe (e.g. Poland, Germany, Netherlands, Belgium, Denmark etc.) and reflect the intensive nature of agriculture. After two decades of rapid increases in NO_3, there has been a trend in which annual maxima are approaching steady state and even decreasing, whereas minimum values are increasing;
- The lowest P concentrations are found in the Nordic countries where 91% of stations had annual average P concentrations less than 0.03 mg P /l. Stations with high P concentrations (> 0.5 mg P/l) are found in a band stretching from Southern U.K across central Europe to Romania (U.K, Belgium, France, Germany). This pattern may be attributed to wastewater treatment processes in these countries. P concentrations in Europe have decreased over the last decade as a result of improved wastewater treatment and decreased emissions from households and industry;
- European rivers, reservoirs and lakes are greatly impacted by nutrients from anthropogenic sources. With the exception of the Nordic countries and other remote sites, nitrate, ammonium and P are present in excess quantities at almost all stations within the European monitoring network. The same situation applies to coastal and marine monitoring stations in the Baltic, Mediterranean, Black and North Seas where nutrient loading from land-based sources has increased ambient levels of N and P;
- Terrestrial ecosystems such as forests and grasslands have also been affected by anthropogenic nutrient inputs, mostly attributed to atmospheric deposition of NO_x; and
- Although not quantified in terms of trends and magnitude, these nutrient increases have caused a wide array of water resource problems throughout countries of the European Union.

3.5.2 Policy and Approach

Concern about elevated nutrient concentrations and adverse eutrophication effects has prompted many strategies at international, national and local levels. An important element of these strategies are the goals set, particularly numeric targets (e.g. 50% reduction in nutrient loads or complete installation of wastewater treatment plants) since these allow for progress to be measured (EEA 1999). Some of the major measures and actions in the European Community over the last 20 years have included:

- Strategic
    - Goals established for what is desired;
    - Target reductions in nutrients;
    - Environmental quality standards; and
    - NO_X standards.
- Point Sources
    - Point source reductions to water;
    - Waste water tertiary treatment;
    - Industry best available technology; and
    - Reduction polic.
- Agriculture
    - Controls on agriculture;
    - Manure restrictions;
    - Manure storage;
    - Silage storage;
    - Fertiliser restrictions;
    - Cultivation; and
    - Financial instruments.
- Products
    - Eco-labelling; and
    - Detergents.
- Atmospheric inputs
    - Atmospheric sources;
    - BAT in industry;
    - Voluntary agreements;
    - Combustion installations; and
    - Traffic.

Most of the above measures, and others, have been incorporated into legislation, and or international agreements.

The European Union 5th Environmental Action Programme introduced several significant measures requiring member countries to carry out certain actions. These have included:

- A 30% reduction in NO_X emissions;
- Regional targets for ammonia emissions;
- An action programme for integrated groundwater protection and management;
- A 1991 Nitrate Directive ((91/676/EEC) to reduce or prevent pollution of water caused by application of inorganic fertilizer and manure on farmland;
- A 1991 Urban Wastewater Treatment Directive (91/271/EEC) to reduce pollution from domestic effluents. This sets emission standards for urban wastewater discharge and requires the stepwise introduction of comprehensive treatment facilities. Standards for total N and P are related to the size of the population of the area serviced and the designation of sensitive receiving areas. A technical compliance date of 1993 was set, but this has subsequently been extended several times (currently set at 2005); and
- A Water Framework Directive that will introduce ecological criteria into performance measures and mean that one of the key criteria for judging compliance will be on the attainment of "good ecological status".

Although many of the EEC member countries have been unable to completely fulfill obligations to the above, it is evident that nutrient enrichment and eutrophication still have a relatively high priority in the EU. This is evidenced by:

- The implementation of these Directives by some countries, and the large budgets allocated for implementation (SCOPE) 1999);
- Countries such as Germany, Netherlands and Denmark attempting to designate all their waters as being nutrient sensitive;
- Continued monitoring and research of aquatic ecosystems and their eutrophication status (e.g. EEA 1994, 1998; Heathwaite *et al.* 1996; Moss *et al.*1996); and
- Evidence of an arrestation of upward trends and an improvement in certain regions of Europe.

There are numerous international commissions and agreements that deal with the protection of specific river systems and the marine environment from eutrophication. These are agreements to restrict the discharges of nitrogen and phosphorus. Some of these include:

- The Helsinki Convention (HELCOM) to protect the Baltic Sea (requiring a 50% reduction in nutrient loads);

- The Paris and Oslo Convention (OSPAR) to protect the North Sea and Atlantic (requiring a 50% reduction in nutrient loads);
- The Barcelona Convention to protect the Mediterranean Sea;
- Danube Action Plan;
- Rhine Action Plan;
- Elbe Action Plan;
- Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1996); and
- Strategic Plan for the Rehabilitation and Protection of the Black Sea.

Most of the member countries have their own eutrophication strategies that focus on reducing and managing the impacts of eutrophication (e.g. in the United Kingdom – Environment Agency 1998). It is accepted that the general mechanisms of nutrient enrichment are understood, that nutrient reduction needs to be implemented. However, costs and benefits appear to be the major policy stumbling block that is preventing wider implementation of many EC Directives in Europe.

3.5.3 Research

Most countries of the EU have supportive research programmes that are examining some aspect of eutrophication. Because of the wide-ranging nature of the topic, as well as the diversity of countries involved, it is not possible to provide any exhaustive analysis. Some of the themes and topics that are currently receiving support, or that have been cited as being of special interest, include (Environment Agency 1998; EEA 1999; http://www.environment-agency.gov.uk/):

- Cause – effect relationships;
- Costs of eutrophication control measures;
- Evaluation of aquatic ecosystem status – the selection and use of eutrophication indicators;
- Monitoring and evaluation of the impacts and benefits of current eutrophication control measures;
- Information management systems;
- The process of eutrophication in running freshwaters, and saline/marine waters;
- Mechanisms that deliver diffuse nutrients to aquatic ecosystems; and
- Phosphorus loss from agriculture.

3.6 Summary points

1. The scan has indicated that eutrophication is still a major water resource problem in most of the industrialized countries (e.g. USA, Canada, European Union Countries, and Australia). All of these countries have recognised that the issue is a strategic environmental problem and have developed appropriate strategies to minimize nutrient inputs into the aquatic environment. The problem does not appear to have as high a priority in less industrialized countries of South America, Asia and Africa. In Europe and North America there is a strong environmental and recreational value attached to water resources.

2. The EEC, Canada, Australia, the USA, and some countries of the EEC have all recently undertaken reviews of eutrophication, utilising highly participative and collaborative approaches. They have been able to assess previous policies, quantify the extent of the problem and, through broad participation of society, develop accepted national strategies. These strategies have mobilized institutions (academic, parastatal, governmental, business and non-governmental) to address the problem. Research and monitoring activities form an integral part of their strategies and are geared towards quantifying nutrient sources, their impacts, and assessing the efficacy of policy and its implementation.

3. The European region is extremely interesting as it has many international water bodies (freshwater and marine) and rivers that are common to several countries, both members and non-members of the EEC. Regulatory directives and international agreements on nutrient reduction have been set in place. Some countries of the EEC have been unable to meet their obligations to nutrient reduction targets that were set nearly 10 years ago. Economic and social considerations appear to be the cause of this.

4. Eutrophication management strategies have been developed to incorporate all aquatic ecosystem types (running waters, standing waters, wetland areas, estuaries and coastal waters). In some countries the nutrient waste management problem is seen as being much wider than eutrophication, in that terrestrial ecosystems (wetlands, forests and soils) have also been impacted, mainly through atmospheric sources.

5. It is recognised in the industrialised countries that success in eutrophication management lies in the acceptance of certain perspectives. These include:
   - Cultural eutrophication is reversible;

- There is no quick fix. The problem requires a long-term approach;
- The issue requires a collaborative approach between government, business and communities. However, government must play the lead facilitation role;
- The issue cannot be solved by a single technical intervention. The problem requires the implementation of a suite of actions (social, economic and technical); and
- Transparent research and monitoring activities are prerequisites to the decision-making that is required.

4. TOWARDS EUTROPHICATION POLICY AND RESEARCH IN SOUTH AFRICA

4.1 Extent of the Eutrophication Problem in South Africa

Eutrophication surveys, conducted in the 1970s, indicated that cultural eutrophication of aquatic ecosystems was widespread throughout South Africa (Toerien 1974; Toerien *et al.* 1975; Noble and Hemens 1978). However, the most severe problems were experienced in the more developed and industrialized areas (Toerien *et al.* 1975). These included:

- Rivers draining north of Johannesburg and Pretoria (e.g. The Jukskei-Crocodile and the Pienaars);
- The Shongweni Dam in Kwazulu-Natal;
- Rivers draining south of Johannesburg into the Vaal River (e.g. Klip River and Blesbokspruit);
- The Buffalo River in the Eastern Cape

The surveys also indicated that, based on their P loading, some reservoirs (e.g. Hartbeespoort, Rietvlei and Roodeplaat) ranked as some of the most eutrophied in the world (Walmsley *et al.* 1975; NIWR 1985). Since that time, there have been few published studies that have reported on whether the eutrophication status of South Africa's aquatic ecosystems has improved or worsened. However, a recent unpublished study by the DWAF Institute for Water Quality Studies has provided evidence that eutrophication is as widespread in South Africa now as it was 25 years ago (Van Ginkel, personal communication [3]). The study also provides evidence that there have been some positive trends in the reduction of nutrient loads, and eutrophication status, of several reservoirs. At the same time, some reservoirs have shown little improvement, whilst others have shown deterioration.

During this study, communication was made with several agencies involved in service provision or research. These included:

- Rand Water
- Umgeni Water
- Cape Metropolitan Council
- Department of Water Affairs
- CSIR

[3] Carin van Ginkel, Institute for Water quality Studies, DWAF, Pretoria

- University of the Orange Free State
- University of Potchefstroom

The responses indicated that eutrophication is regarded as a common water quality problem in many water supply and recreational systems throughout the country. The main problems were cited as:

- Nuisance algal blooms, some of which were toxic;
- Taste and odour problems caused by certain algal species;
- Filter clogging of domestic water treatment filters;
- Increased treatment costs; and
- Nuisance growths of aquatic macrophytes.

4.2 South Africa's Policy and Approach to Eutrophication

South Africa initially tackled the problem of eutrophication by gaining knowledge on the extent of the problem in the country (e.g. Toerien *et al.* 1975; Walmsley *et al.* 1975). Then, based on best available wastewater technology, set a 1 mg/ℓ P special standard for effluent discharges in sensitive catchments (Taylor *et al* 1984). The Department of Water Affairs promulgated the 1 mg/ℓ -P effluent discharge standard in 1980 when an amendment of the standards for the discharge of industrial waste water into a water resource prescribed in terms of Section 21(1)(a) of the Water Act, 1956, was announced in Government Notice No.1567. This announcement declared a special standard for phosphates in industrial wastewater and read as follows:

"Waste water or effluent produced by or resulting from the use of water for industrial purposes and which drains to any portions of a river mentioned in Schedule 2 or any tributary of such a river within the catchment areas or portions thereof described in the Schedule, shall not contain soluble ortho phosphate (as P) in a higher concentration than 1.0 milligram per litre"

The sensitive river systems include:

- *Vaal River upstream and inclusive of the Bloemhof Dam;*
- *Pienaars and Crocodile Rivers upstream of their confluence;*
- *Great Olifants River upstream and inclusive of the Loskop Dam;*
- *Umgeni River upstream of the influence of tidal water;*
- *Umlaas River upstream of its point of discharge into the sea;*
- *Buffalo River upstream and inclusive of Bridle Drift Dam;*

- *Berg River upstream of the influence of tidal water."*

Representations from local authorities who experienced a multitude of problems (insufficient knowledge, experience, finances and/or trained operators) led to an extension of the implementation period up to 1 August 1985. Subsequently the Department decided to:

- Only implement the P-Standard in the Vaal River catchment up to the Barrage and in the Crocodile River catchment up to the confluence of the Crocodile and Pienaars Rivers;
- Grant a further three years exemption, until August 1988, from complying with the 1 mg/ℓ P-Standard in the remaining catchments.

Despite recommendations from scientists for a management policy that incorporated receiving water objectives and P load allocations (Toerien 1977;Walmsley and Butty 1980; Grobler and Silberbauer 1984), South Africa has pursued a source directed approach to eutrophication management. This approach is somewhat contrary to policy directives on water quality management strategies that have been published by DWAF (Van der Merwe and Grobler 1989;DWAF 1991; DWAF 1995). In 1988 the government introduced a receiving water quality objective of 130 μg/ℓ total phosphorus for reservoirs in these sensitive catchments (DWAF 1988). It is unclear as to how this figure was derived or as to whether it represented, or still represents any official government policy or regulation. There is little published evidence after 1988 of the value being publicly discussed or officially incorporated into management plans for eutrophication control. Van Ginkel (personal communication [3]) has made use of it in a recent analysis to demonstrate the trophic condition of reservoirs relative to this concentration.

Since 1985, there is evidence to indicate that eutrophication has been given a low priority status by government. This may be concluded on the basis of the following:

- There has been a widespread non-compliance of the 1 mg P/ℓ standard by many wastewater treatment plants in the sensitive areas (Van Niekerk 2000). The extent of compliance is not well-monitored or documented and there have been few prosecutions for this non-compliance;
- Although there is evidence to indicate a reduction in the ambient P concentrations in certain reservoirs, there appears to have been little improvement of the general eutrophication problems being experienced in receiving water systems (e.g. Chutter 1991; DWAF 1999);

[3] Carin van Ginkel, Institute for Water quality Studies, DWAF, Pretoria

- There has been a large gap between water quality policy and its implementation on general eutrophication control. The government did at one stage consider introducing a receiving water quality objective, and a waste load allocation approach to nutrient control (e.g. Van der Merwe and Grobler 1989; DWAF 1991; DWAF 1995), but this was not applied (Quibell *et al.* 1997);
- There has been little effort to review eutrophication policy in the light of monitoring information (e.g. Rand Water 1998). A recent DWAF draft discussion report advocates a *review of eutrophication management policies and strategy, as well as the initiation of* specific projects (DWAF 1999). At time of writing, it is not clear as to what position DWAF has adopted *apropos* the proposals;
- Management capacity on eutrophication issues has become diminished throughout the country as staffing transformation and human resource turnover within institutions has meant that there is limited background knowledge or practical experience of the problem. There have been few capacity-building special projects aimed at rehabilitating the eutrophication status of any aquatic system. The country has regressed in terms of its capacity and ability to deal with eutrophication (Moss 1999);
- Scientific and technical publications on the topic have been almost non-existent during the 1990s, meaning that decision-makers have not been exposed to information on the subject. There have been few governmental documents available to the public. This is in contrast to the 1970s and 80s when numerous publications were available for this purpose;
- There have been relatively few eutrophication research and capacity building activities supported by state agencies such as the Water Research Commission or the National Research Foundation (formerly the Foundation for Research Development). As a consequence, research and training activity at South Africa's institutions has become eroded. There has also been an adverse impact on the flow of international information on eutrophication reaching the country. The problem is further compounded by the fact that the agencies have adopted a project-based approach to research that has not allowed for any meaningful programme to develop. This is a great pity as in the period 1975 to 1985 South Africa was regarded as one of the leading country's in eutrophication management and research (Moss 1999). In addition, policy-making has not been able to derive the appropriate benefits from research activity; and
- During a project aimed at seeking solutions to the ongoing eutrophication problem at Hartbeespoort Dam (see NIWR 1975, NIWR 1985), delegates to a workshop identified social and management issues as being the major stumbling blocks to improving the

reservoir's water quality condition (Rand Water 1998). After a two-year period, it is unclear as to what recommendations from the project have been implemented by the stakeholders (Walmsley *et al.* 2000).

The low priority currently given to eutrophication cannot be ascribed to the absence of any national policy on environmental and water resource management (DWAF 1991; DWAF 1995; Fuggle and Rabie 1992; Treurlings 1993a 1993b). The next section demonstrates that current national policy implicitly incorporates eutrophication as a key pollution and waste management issue. As such, it is surprising that it has received such apparent low attention.

4.3 South African Environmental and Water Resource Policy

In South Africa there are numerous natural resource regulations that relate to the management of the environment and water resources (Fuggle and Rabie 1992; Treurlings 1993a 1993b). Apart from the South African Constitution, two of the main overarching instruments that provide an indication of policy and regulations for the aquatic environment are: the National Water Act (NWA - Act 36 of 1998) and the National Environmental Management Act (NEMA - Act 107 of 1998). Both of these Acts, recently-developed through wide consultation with South African society, provide a reflection of the policies that the South African Government has adopted. The principles outlined in both Acts are fairly similar and indicate that sustainable development, through sound management of natural resources, waste, and control of pollution, has been adopted as the country's approach to water resource management. It should, therefore, be implicit that management of cultural eutrophication has been catered for in these overarching policies.

The most appropriate management system is one in which research activities contribute to the development and evaluation of policies and their associated implementation actions and programmes. This section therefore highlights aspects where both of these Acts are appropriate to eutrophication and its management, thus setting a basis for research and capacity building.

4.3.1 *The National Environmental Management Act (NEMA -Act 107 of 1998)*

In NEMA, the environment is defined as ***"the surroundings within which humans exist and are made up of:***

- ***The land, water and atmosphere of the Earth;***
- ***Microorganisms, plant and animal life;***

- ***Any part or combination of the above and the interrelationships among and between them; and***
- ***The physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being."***

NEMA advocates that the principle of sustainable development is paramount and that all development must be socially, environmentally and economically sustainable. Sustainable development requires consideration of all relevant factors, including that:

- The disturbance of ecosystems and loss of biological diversity are avoided, or where they cannot altogether be avoided, are minimised and remedied;
- Pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied;
- The disturbance of landscapes and sites that constitute the nation's heritage is avoided or, where it cannot be altogether avoided, is minimised and remedied;
- Waste is avoided or, where it cannot be altogether avoided, is minimised and reused or recycled where possible and otherwise disposed of in a responsible way;
- The use and exploitation of non-renewable natural resources is responsible and equitable and takes into account the consequences of depletion of the resource;
- Development, use and exploitation of renewable resources and the ecosystems of which they are part do not exceed the level beyond which their integrity is jeopardised;
- A risk-averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions;
- Negative impacts on the environment and people's environmental rights be anticipated and prevented, and where they cannot be altogether prevented, are minimised and remedied;
- Environmental management must be integrated and that the best practicable option is selected;
- Environmental justice must be pursued;
- There must be equitable access to resources;
- Responsibility for the environmental health and safety consequences of a policy, programme, project, product, process, service or activity exists throughout its life cycle;
- The participation of all interested and affected parties in environmental governance is promoted;

- Decisions must take into account the interest, needs and values of all interested and affected parties;
- Community well-being and empowerment must be promoted through environmental education and the raising of awareness;
- Decisions must be taken in an open and transparent manner and access to information must be provided in accordance with the law;
- There must be intergovernmental co-ordination and harmonisation of policies, legislation and actions;
- The environment is held in public trust for the people and the beneficial use of environmental resources must serve the public interest;
- The costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible; and
- Sensitive, vulnerable, highly dynamic or stressed ecosystems such as coastal shores, estuaries, wetlands, and similar systems require specific attention especially where they are subjected to significant human resource usage and development pressure.

NEMA also makes provision for all spheres of government (central, provincial and local) to participate cooperatively in the governance of the environment. To this end, NEMA has called for all national and provincial departments involved in any aspect of natural resource or environmental management to generate both Environmental Implementation Plans (EIPs) and Environmental Management Plans (EMPs). The purpose of this is to give effect to the principle of cooperative governance in order to support the protection of the environment across the country as a whole, and the monitoring of the achievement, promotion and protection of a sustainable environment.

The definition of the environment includes the remit of aquatic ecosystems and therefore the NEMA principles apply to all issues affecting water resources. Eutrophication is therefore an environmental problem that should be incorporated within the implementation of NEMA. There is thus an obligation for all relevant departments to cooperate in producing policies, strategies and programmes that manage eutrophication and its impacts.

4.3.2 *The National Water Act (NWA – Act 36 of 1998)*

The NWA (completely replacing the Water Act of 1956) promotes sustainability and equity as the central guiding principles in the protection, use, development, conservation, management and control of water resources. Although no mention is made of nutrient enrichment in the Act, there are several features to the Act that merit the inclusion of eutrophication considerations. These include:

- **The National Water Resource Strategy**. It requires the progressive development, after consultation with society at large, of a national water resource strategy. The national water resource strategy provides the framework for the protection, use, development, conservation, management and control of water resources for the country as a whole. It also provides the framework within which water will be managed at regional or catchment level, in defined water management areas. The national water resource strategy, which must be formally reviewed from time to time, is binding on all authorities and institutions exercising powers or performing duties under this Act. ***Nutrient management considerations should form part of the national strategy***.
- **Catchment Management Strategies**. The NWA devolves responsibility to catchment management agencies to progressively develop catchment management strategies for the water resources within their jurisdiction. All catchment management strategies must be in harmony with the national water resource strategy and set principles for allocating water to existing and prospective users, taking into account all matters relevant to the protection, use, development, conservation, management and control of water resources. ***Nutrient management strategies should form part of all catchment management strategies.***
- **The Reserve.** This is a volume of water that needs to be maintained for two purposes. The basic human needs reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class of the resource. The government is required to determine the Reserve for all or part of any significant water resource. Once the Reserve is determined for a water resource it is binding in the same way as the class and the resource quality objectives. ***Eutrophication issues should form a strong consideration on the assessment of the reserve.***
- **A National Classification System.** The NWA calls for the development of a system to classify the nation's water resources and thus requires guidelines and procedures for

determining different classes of water resources. The system for classifying water resources may: establish guidelines and procedures for determining different classes of water resources; establish procedures for determining the Reserve; set out water uses for instream or land-based activities which activities must be regulated or prohibited in order to protect the water resource; and provide for such other matters relating to the protection, use, development, conservation, management and control of water resources.

The government is required to use the classification system to determine the class and resource quality objectives of all or part of water resources considered to be significant. The purpose of the resource quality objectives is to establish clear goals relating to the quality of the relevant water resources. Once the class of a water resource and the resource quality objectives have been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this Act. ***The classification system should give due consideration to nutrient enrichment and trophic status of specific water body types (e.g. rivers, wetlands, reservoirs, lakes, estuaries and coastal waters).***

- **Pollution Prevention Measures**. The NWA deals with pollution prevention, and in particular the situation where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken, the Catchment Management Agency concerned may itself do whatever is necessary to prevent the pollution or to remedy its effects, and to recover all reasonable costs from the persons responsible for the pollution. ***Eutrophication is a form of pollution, and its management should be incorporated into these pollution control considerations***. Some of the pollution prevention measures include measures to:
    - Cease, modify or control any act or process causing the pollution;
    - Comply with any prescribed waste standard or management practice;
    - Contain or prevent the movement of pollutants;
    - Eliminate any source of the pollution;
    - Remedy the effects of the pollution; and
    - Remedy the effects of any disturbance to the bed and banks of a watercourse.

- **Establishment of Information Management Systems**. The NWA requires government to establish national information systems on the quantity and quality of all water resources. ***Eutrophication management issues and indicators should be included on any such***

developed information system (s) at both national and water management area (catchment) level.

4.4 Towards a Eutrophication Management Policy

A schematic framework for eutrophication policy setting, research, capacity building, and management is presented in Figure 4.1. The framework is based on the current principles and approach recommended by NEMA and NWA. It is also consistent with the way in which DWAF intends to implement its obligations to the NWA. In this framework:

- National policy on environment and water resources is based on the desire to achieve sustainable use of the country's water resources by protecting quality, volume and environmental integrity of surface and ground water systems;
- Implementation of the policy, apropos water quality (and hence eutrophication), requires the presence of a national water quality management strategy (e.g. DWAF 1991) and national guidelines (e.g. DWAF 1995);
- The national strategy and the guidelines are then used to define catchment-specific strategies and management plans which are aimed at achieving resource-directed water quality objectives that are approved by stakeholders. The involvement of stakeholders and communities is crucial;
- Following implementation of an action plan and monitoring of selected indicators, it is possible to assess whether a particular approach has been successful. There is therefore a feedback loop that has input back into both catchment and national approaches;
- Most of the processes and steps require human resource capacity, as well as research and/or monitoring activity.

Quibell *et al.* (1997) conclude that in the past, the government was unable to resolve the "process" part of the framework, i.e that part which is intimately associated with the communities (interested and affected parties) affected by the problem, and the design and implementation of relevant interventions. Although much of the NWA is devoted to specifying mechanisms to solving this general problem, there is a need to be more specific about eutrophication. It is considered relevant that the South African government should give consideration to formally incorporating the following points within its water resource management policies. These include:

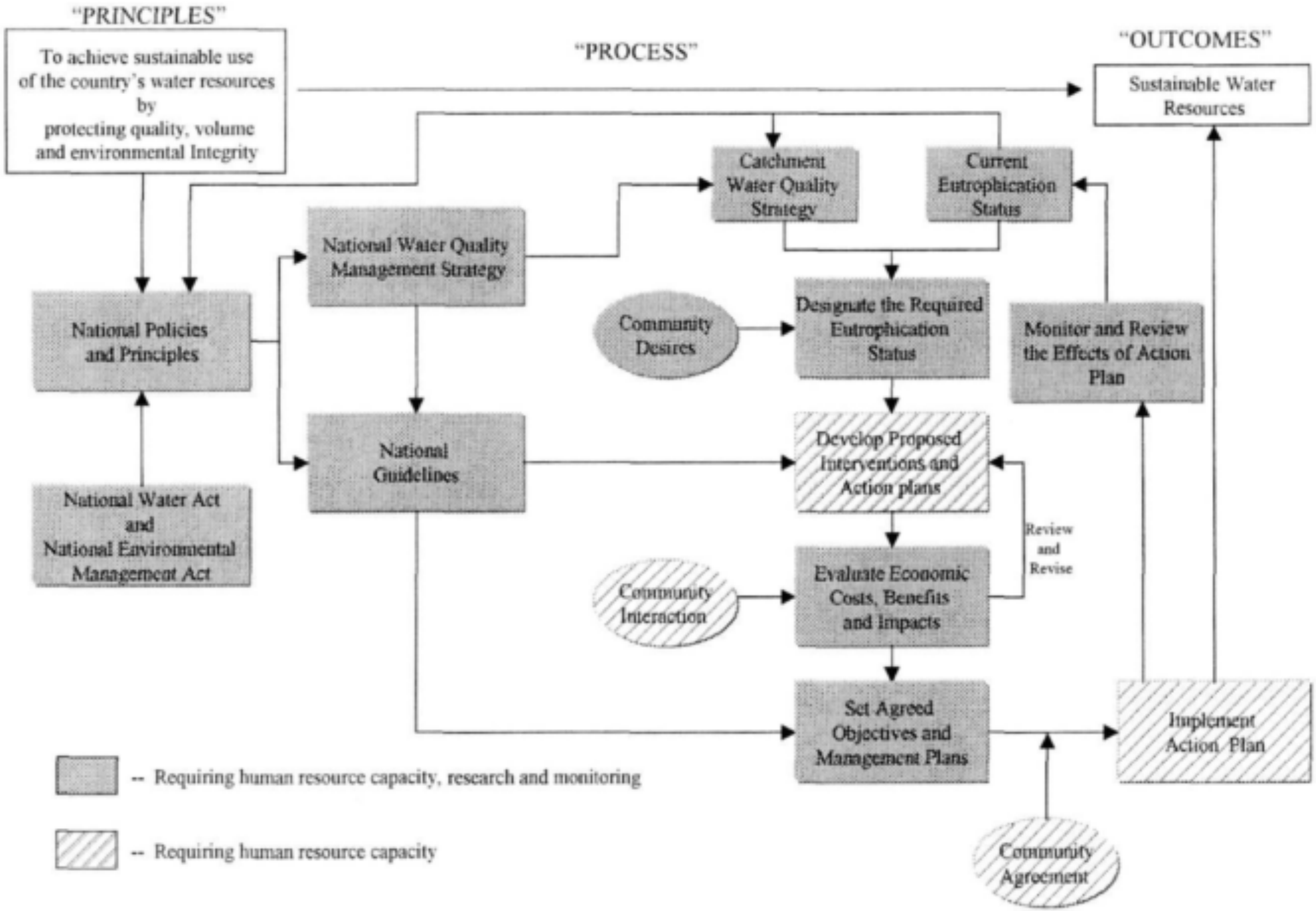

Figure 4.1: Flow diagram to illustrate the management processes required to close the gap between policy setting and implementation of eutrophication action plans. Inputs and processes requiring research and capacity are indicated

- The National Water Strategy should include a national strategy to minimize the flow of anthropogenic nutrients into aquatic ecosystems, as well as to manage the impacts of eutrophication where it has already reached unacceptable proportions;
- Catchment Management Strategies, developed by the Catchment Management Agencies, should all include catchment-based strategies to minimize nutrient inputs to the aquatic environment and manage the impacts of eutrophication;
- *There is a need to develop guidelines that specify how eutrophication should be managed* both at national and catchment levels. These aspects are missing from the current set of DWAF water quality guideline documents;
- The National Classification system must incorporate aspects of receiving water trophic status within each of the classes. Consideration should be given to differentiation between running waters, standing waters, wetlands, estuaries and coastal waters as the impacts of nutrient loading are different for each. The extent of anthropogenic influence should be based on a reference or natural background level of eutrophication;
- The government should set resource quality objectives that specify the acceptable maximum limits to eutrophication problems for all receiving waters. Appropriate measures and control programmes should be put in place to ensure that these objectives are met. This includes the adoption of a range of regulatory mechanisms (voluntary, collaborative, educational and economic) to reduce nutrient inputs and effect rehabilitation/remediation projects. Costing should follow the polluter pays principle and be based on exceedance of discharge standards and/or assessed contribution to the eutrophication load;
- The government has incorporated land-based activities into the ambit of the New Water Act. Therefore nutrient and eutrophication control measures should be applied to all products and activities that are potential sources of nutrient emission (e.g. emissions to the air; emissions from diffuse sources such as municipalities, dense settlements and agriculture);
- The central government, and the national network of Catchment Management Agencies should introduce an appropriate national eutrophication monitoring and information system that has the capability of:
    - Measuring and monitoring the inputs of nutrients from anthropogenic and natural sources;
    - Measuring and assessing the impacts of these inputs (both separately and cumulatively) on receiving waters that are used by society;

- Measuring and assessing the performance of remediation/rehabilitation measures; and
- Reporting regularly (e.g. every 5 years) and transparently on the eutrophication status of South Africa's receiving water systems so as to demonstrate positive and negative trends both on a catchment and a national basis.

N.B The Water Research Commission has recently commissioned a project, to be commenced in 2000, on the development of a monitoring and information management system for eutrophication in South Africa (Du Plessis, personal communication[4])

- Central government, in collaboration with the network of established Catchment Management Agencies and parastatal research agencies, should collectively and cooperatively initiate a long-term national eutrophication research and capacity development programme. This programme would have the role of:
  - Investigating special priority topics on the eutrophication issue;
  - Training both new and established scientists in the concepts of the eutrophication problem and their solutions;
  - Evaluating and contributing to policy on specific eutrophication issues;
  - Promoting the science and technology of eutrophication as a water resource management problem. This should include both social and economic perspectives;
  - Promoting interaction between scientists, trainees, institutions and decision-makers; and
  - Generation and allocation of funds to support the above activities.
- The eutrophication problem should not be viewed as being solely a DWAF problem. The management of eutrophication should involve a partnership approach to management, at both local and national level since the solutions are beyond the jurisdiction of any one regulatory body. The co-operation should extend to all stakeholders who are involved with generating nutrients or impacted by them. This includes relevant government departments, industry and affected communities. The government should consider the setting up of a governmental/industry/community eutrophication task group to promote the partnership process, as well as the numerous other activities that this problem requires.

[4] Meiring du Plessis c/o Water Research Commission, Pretoria

4.5 Eutrophication Research Needs

There are numerous ways in which research can support the development and implementation of policy. Research activities have numerous benefits for policy development (and hence wise resource management) as they contribute to:

- Evaluating the implementation of previous policy;
- Developing new policy;
- Developing and testing new approaches and methods;
- Assisting with the development of human resources and capacity throughout the country;
- Acting as focal points for debate between decision-makers; and
- Improving information flow and communication.

Eutrophication management in South Africa has become somewhat incapacitated as a result of an inability to transform policy into practice (Quibell *et al.* 1997). Research is a vehicle by which this capacity can be revitalised.

It is perhaps pertinent to mention, and perhaps comment on previous research approaches. Early eutrophication research work of the 1970s, that concentrated on assessing the status of the problem in many water bodies throughout South Africa (e.g. Toerien *et al.* 1975; Walmsley and Butty 1980a), was never allowed to develop into a tool that provided a national long-term picture. Subsequent research of the 1980s that became focused on the detailed characteristics of one system (Hartbeespoort Dam- NIWR 1985) also never allowed for a national approach. The focused impoundment approach is only useful if decision-makers are looking to implement interventions for that particular system as a role model. In the case of Hartbeespoort Dam, the record shows that research was never followed up by any implementation programme (Rand Water 1998).

This review therefore also provides an opportunity to promote the principle that eutrophication is indeed a national problem, and it is a long-term issue. Research approaches should therefore be geared to providing information on the long-term implications of the problem.

There are many research areas that need to be supported, some of which require long-term perspectives. Although this study has examined some current international research approaches, it is felt that these have not altered radically over the years in terms of answering basic key questions. Many of these questions and approaches were published many years ago in a seminal report on inland water ecosystems in South Africa (Noble and Hemens 1978). Communication with agencies and individuals during this study has provided a similar list to that of Noble and Hemens (1978), indicating that the issues are equally as relevant today as they were some 22 years ago. Some of the topics that need to be considered for support (not in any order of priority) include:

1. Assessment and prediction of eutrophication problems in freshwater, estuarine and coastal *environments*
    a. Social and economic costs of eutrophication and its side effects;
    b. Methods to assess public and community perceptions of eutrophication;
    c. Development of national and catchment-based indicators for assessing eutrophication;
    d. Criteria to assess trophic status of receiving waters, particularly for use in the classification system and the calculation of the Reserve;
    e. Procedures to predict and assess eutrophication and its impacts;
    f. Methodology and guidelines for the diagnosis of the eutrophication status of an aquatic system and the best interventions/options for remediation; and
    g. Development of systems models for eutrophication management.
2. Nutrient loading
    a. Methods for measuring and monitoring nutrient loads in rivers;
    b. Integrated estimations of N and P compound loadings from all point and non-point sources for catchments;
    c. Assessment of nutrient loading from specific non-point sources (e.g. dense settlements, urban areas, and agricultural systems);
    d. Assessment of nutrient loading from aerial deposition;
    e. Assessment of nutrient transformations and losses between sources and receiving systems (the role of soils, vegetation and other organisms); and
    f. Nutrient budgets for specific ecosystems
3. The role of wetland systems in retaining nutrients
4. Nutrient dynamics in reservoirs
    a. Nutrient cycling in the water column;
    b. The role of sediments in retaining and releasing nutrients;
    c. The dual roles of N and P in stimulating algal production
5. Nuisance plant growths
    a. Factors causing the appearance of nuisance plant growths (algae and macrophytes) in aquatic systems;

   b. Toxic algae, frequency and causes of appearance, and impacts on human health;
   c. The role of nitrogen-fixing algae; and
   d. Algae that produce tastes and odours
6. General factors that moderate the impacts of nutrient loading on aquatic ecosystems (e.g. hydrology, suspensoids, climate, etc.)
7. Assessment and experimental development of eutrophication management techniques (amongst others):
   a. Management intervention techniques with communities and stakeholders
   b. Product replacement (e.g. phosphate replacement in detergents);
   c. Land-use management (e.g. agricultural practices, buffer zones);
   d. Wastewater treatment;
   e. Treatment of water from eutrophic systems;
   f. In-stream techniques;
   g. Aeration;
   h. Sediment manipulation;
   i. Chemical control; and
   j. Physical removal.
8. Development of information management systems to allow for better processing and reporting of information.

It is self-evident that all of the above topics have a role to play in the setting and evaluation of policy, as well as the development of capacity throughout the network of South African organizations (and their personnel) that are concerned with eutrophication and its management. However, for many reasons it would be impossible for all these topics to receive immediate attention. There is therefore a need to set some perspective on what should be the priority areas for immediate support by government agencies. This perspective can perhaps be formulated by the viewpoint that ***the country's water resource managers need to develop national strategies and guidelines for eutrophication control, but do not have relevant quantitative knowledge of:***

- ***The national eutrophication problem in terms of its extent and trends;***
- ***The sources of nutrients and the levels entering aquatic systems; and***
- ***The actual social and economic costs of the problem on a national basis.***

Without the above basic knowledge, it is not possible to assess what strategies and resources should be directed at the problem. It is therefore proposed that initial research and capacity development activities should be directed at a national assessment of the eutrophication problem and its socio-economic impacts on the country. This would include all or some of the topics under sections 1 and 2 of the above list and allow for trends to be evaluated. It should also put into place long-term methods and approaches to monitoring the problem on a national basis. Some focus could be directed at the so-called "sensitive catchments" where the problem is known to be more severe.

This does not imply that other issues should be ignored. Other topics that have been mentioned in the above list are more site-specific and possibly could be supported by agencies or organizations (e.g. Water Boards and municipalities) that are impacted by them or wish to implement or test certain approaches.

4.6 The Way Ahead

This review, presented in the form of a discussion document, has been undertaken with the objective of providing South Africa's water resource management community with a perspective of the eutrophication problem, how it is being addressed elsewhere in the world, and how it has been addressed in South Africa. It also attempts to demonstrate the important links between policy and research and what should be done for the future. There are many identified deficiencies in previous and current approaches to eutrophication management and research in South Africa. There is a need to debate whether these are "real" or merely "perceived", as well as to formulate approaches to closing some of the "real" gaps so that the eutrophication problem can receive the attention that it merits.

The document should therefore be seen as an attempt to define a new starting point for policy, management, capacity building and research activities on eutrophication in South Africa. Accordingly, it is proposed that this document should form the basis of a workshop that:

- Is attended by water resource managers (DWAF, Water Boards, municipalities), research and capacity development agencies (National Research Foundation, Water Research Commission), and key researchers;
- Has objectives that include, amongst others:
    - A presentation and discussion of the report's findings;
    - Agreement on the extent and nature of the "real" gaps in eutrophication policy and its implementation;
    - The development of cooperative structures and mechanisms to address the gaps;
    - Identification of research priority areas for national support; and

- The development of a programme of action to ensure that there is follow up to the workshop's findings and recommendations.

4.7 Summary points

1. Eutrophication, recognised as a priority water resource management problem in South Africa more than 30 years ago, is still widespread. This is particularly so in the more populated industrialized areas of the country. Many water resource management agencies experience the problem on a daily basis in water treatment works and recreational water bodies. The national water resource monitoring system does not allow for any informed opinion as to whether the problem has increased or decreased in intensity.

2. There is considerable evidence to support the perception that South Africa's policy and approach to eutrophication control has been inadequate over the last 20 years. A lack of input to policy development, monitoring, research, reporting and capacity development has greatly diminished the country's ability to deal with the problem. The apparent low priority given to the issue cannot be ascribed to the absence of any national overarching policy on environmental and water resource management policy. The problem has its roots in the inability of government to undertake the required processes to close the gap between policy setting and the required implementation actions.

3. The National Water Act and the National Environmental Management Act, both promulgated in 1998, carry new perspectives for waste management and eutrophication control. National policy requires that environmental integrity is protected and that waste discharges are minimized. The Water Act, which is more functional, specifies some of the approaches as to how the gap between policy and implementation can be closed. There is however, a need to for the country to remobilize and redevelop its capacity to manage eutrophication.

4. There are several areas where policy on eutrophication requires a more explicit approach. These include:
    - Specifications of a national eutrophication strategy within the National Water Strategy;
    - Specifications of a eutrophication strategy within each Catchment Management Strategy;

- Incorporation of eutrophication concepts within the national Classification System for aquatic systems;
- The setting of resource management objectives that include eutrophication problem criteria;
- The incorporation of land-based control measures into eutrophication policy;
- The development of eutrophication management guidelines;
- The development and management of a eutrophication monitoring information management system;
- The development of a long-term research and capacity building programme to support all other activities; and
- The acceptance and commitment of all parties to co-operative governance on eutrophication management and control.

5. There are numerous research areas that require support. It would be impossible for all of the identified topics to be supported by any one agency. It is felt that immediate national research should be directed at: quantitatively assessing the eutrophication problem in terms of its extent and trends; the sources of nutrients and the levels entering aquatic systems; and the actual social and economic costs of the problem on a national basis.

6. There is a need for South Africa to develop a new approach to eutrophication policy, management and research. It is proposed that this discussion document be used as the basis for an interactive workshop that has the objectives of: discussing the report's findings; agreeing on the extent and nature of the "real" gaps in eutrophication policy and its implementation; developing cooperative structures and mechanisms to address the gaps; identifying research priority areas for national support; and, developing a programme of action to ensure that there is follow up to the workshop's findings and recommendations.

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