

**ECOLOGICAL AND ECONOMIC
ASPECTS OF TREATING VEGETABLE OIL INDUSTRIAL
EFFLUENT AT DARVILL WASTEWATER WORKS IN
PIETERMARITZBURG**

BY

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I hereby certify that, unless specifically indicated to the contrary in the text, this dissertation is the result of my own work.



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ABSTRACT

The dissertation analyses the economic and ecological aspects of Darvill Waste Water Works (WWW) through key indicators from Sustainable Development Records (SDR). The SDR study identifies disturbances caused by large concentrations of soap, oil and grease (SOG), therefore a framework of proposed solutions to dealing with these problems has also been investigated.

The first component of the study highlights the importance of adequate indicators. Key indicators provide important information that is useful to management and policy makers. The SDR used to analyse the Darvill WWW in Pietermaritzburg provides relevant information for the management of Darvill WWW and Umgeni Water (UW), the City Council and the Department of Water Affairs and Forestry (DWAF). According to the SDR model the Works is identified as a service providing social institution. The operation of this institution affects the community of Pietermaritzburg as well as the surrounding natural environment. SDR uses the key indicators of Effectiveness, Thrift and Margin to analyse the economic and ecological impacts of the service provided. The study incorporates relevant data for Darvill WWW during 1993- 1996.

Effectiveness measures the degree of compliance with national water quality standards as set out by the DWAF. Compliance of the following variables, *E.coli*, Chlorine, Soluble Reactive Phosphate (SRP), Total Suspended Solids (TSS), Conductivity, Chemical Oxygen Demand (COD) and Ammonia were investigated. These variables produce varying trends. Increasing compliance is linked to improved plant efficiency while decreasing compliance is linked to the poor quality of industrial effluent. Industrial effluent containing large concentrations of SOG is a particular problem.

Thrift measures the costs of operating the Works in terms of energy, chemicals, labour and capital. Overall financial, energy and labour thrift declined while chemical thrift increased. Increasing chemical thrift is due to the reduced consumption of chemicals as a result of a greater reliance on the process of biological phosphate removal. Decreasing thrift is related to increased costs of capital, energy and labour due to the deteriorating quality of vegetable oil effluent.

Margin measures the deviation of non-complying samples from water quality standards. Analysis of the data produced varying trends. The following variables were analysed, *E.coli*, Chlorine, SRP, TSS, Conductivity, COD and Ammonia. Marginal difference is studied in an attempt to analyse those samples which do not comply with national standards. Deteriorating quality of industrial effluent seems to be the reason for deviation from the standards. Chemical margin was also studied for the period between 1993-1996. Chemical margin is a comparison between the value of sludge produced and the cost of chemicals used to produce the sludge. The SDR study highlights deteriorating quality of industrial effluent as a cause for concern to Darvill WWW. Proposed management options are investigated to provide a workable solution.

The second part of the study investigates alternate options for handling wet industrial effluent from the vegetable oil industries. These industries were identified as the source of large concentrations of SOG that were entering the Works which impacts negatively on the operational capacity, thereby increasing operating costs and decreasing the quality of the service provided.

Vegetable oil industries were found guilty of discharging industrial effluent that did not meet the City standards into the sewers, they were also charged with illegal dumping into rivers. The study identified the interested and affected parties and alternate solutions were proposed to the problems. Interested and affected parties include UW, Pietermaritzburg City Council, DWAF.

Some of the aspects that were investigated include the local industrial tariff, the drainage By-laws, national legislation, the "polluter pays" principle and the principle of pollution prevention. Economic incentives using economic instruments were reviewed. These include ecotaxes such as marketable/tradable permits and pollution charges. These instruments may allow for more equitable charges thereby promoting the "polluter pays" principle. The use of these instruments may be able to achieve a workable solution but further investigations are necessary.

SDR analysis indicates that Darvill WWW seems to be effectively treating wastewater but operating costs are increasing in order to achieve compliance. These costs are being unfairly borne by the City ratepayers and UW and a more equitable situation is necessary.

INTRODUCTION

There is growing evidence that resource destruction from pollution and over exploitation is occurring on a scale that could endanger the process of economic development in South Africa (SA) and reduce the human well being of present and future generations. Resources such as minerals, water, soil and forests are becoming increasingly scarce on a world wide scale as is the case in SA. There can be no choice between conservation and economic development because both are needed. Therefore it is necessary to find a path to economic development that causes the least environmental damage from pollution, waste and lost options (Fuggle & Rabie, 1994).

The regular control and monitoring of vital resources are important for maintaining sustainable economic development and environmental conservation. Economic and environmental resources are linked. Effective resource management is thus important in establishing and maintaining a progressive nation. Effective resource management can only be achieved if resource use is properly measured and analysed with the assistance of effective and efficient indicators. To achieve a balance between both these issues, it is necessary to be able to measure how the environment is affected and how economic development is affected.

Freshwater is rapidly becoming a scarce commodity in SA due to an increasing demand from growing populations, urbanization, industrialisation and irrigation. In order for water to be better managed and appreciated it must be recognised as a valuable and scarce resource. But past and present development strategies tend to take the availability of water for granted. Few attempts are made to take water availability into account when deciding on sustainable development plans. As with other rapidly developing countries, SA does not recognise the supply of freshwater as a constraint to development. Since SA is a water scarce region, the reuse of effluent is a vitally important supplement to freshwater resources. Effluent, containing pollutants, must be returned to the natural water bodies for reuse after being properly treated. Therefore effective effluent and waste water treatment is necessary (DWAF, 1991).

Sustainable water management for developing areas require reusing water, charging polluting industries for the clean up costs and improving government regulations through command and control and economic incentives. It is also the responsibility of regulating bodies to create a raised sense of discipline in water use but this is becoming an increasingly difficult task as industrialization and development begins to gather momentum.

Industry uses freshwater for cooling, processing, cleaning and removing industrial wastes and most of this water is returned to the natural water cycles, very often heavily polluted with chemicals and heavy metals. Evidence indicates that more stringent pollution control regulation in many Northern American countries has encouraged industry to change systems and considerably reduce freshwater use. This has resulted in the industrial water intake in these countries dropping by 23% during 1978-1983 despite a 6% increase in the number of industrial installations. It is estimated that Asia, Africa and Latin America will be using 3-5 times more water by the year 2000 than they do now (Holmberg, 1991). This could result in severe problems for SA, since effective regulation and local awareness for the need to conserve scarce resources is relatively low. A more judicious use of water is a prerequisite for and part of sustainable development (Holmberg, 1991).

Many industries generate byproducts and waste during their production processes and they need some way to dispose of these wastes. As the environment is considered to be a common resource or free good, the cheapest way for industries to get rid of their waste products is by dumping them directly into streams, the ocean or other pristine areas. The situation in Pietermaritzburg has seen a tendency to encourage economic development through increased industrialisation. A number of industries as well as domestic households discharge effluent into the City's sewers. This effluent can contain high levels of potentially environmental damaging substances including pathogens such as micro-organisms (*E.coli*) and harmful chemicals such as Ammonia and Chlorine. If this effluent is not adequately treated before being discharged back into freshwater sources, it could pollute water sources to the extent that they are not fit for human or ecological consumption. All life forms dependant on these water sources are affected and the ocean into which this water flows becomes polluted. Darvill Waste Water Works (WWW) is the waste water treatment plant that serves the greater Pietermaritzburg area.

Umgeni Water (UW) owns and operates the Works and they are concerned about the capacity of the Darvill W W W to cope with the quality and quantity of wet¹ industrial effluent that is being produced. Although industrial effluent in Pietermaritzburg is treated, the rate paying public appears to be subsidising the costs of this treatment. Evidence indicates that polluters specifically the vegetable oil industries are not responsible for clean up costs. These industries are responsible for pollution and illegal disposal of industrial wastes but they are not paying clean up costs. The current situation is unfair and inequitable to the ratepayers of Pietermaritzburg and UW.

The aims of this dissertation are twofold. Firstly to analyse the ecological and economic aspects of Darvill W W W and secondly to outline the framework of management options for addressing some of the pollution problems associated with the vegetable oil industries in Pietermaritzburg.

The effectiveness of Darvill W W W will be assessed using Sustainable Development Records (SDR) as indicators that allow measurement of the effectiveness, thrift and margin of the Works. The need to develop reliable indicators is emphasised as well as estimating and explaining trends in key SDR indicators for Darvill W W W. Recently the operating capacity of Darvill W W W has been affected by the deteriorating quality of incoming waste water. Non-compliance with *E.coli*, Ammonia and Soluble Reactive Phosphate (SRP) levels are some water quality problems that have arisen. UW has incurred increased costs due to increased capital, labour and energy costs to treat waste water. Since the quality and quantity of domestic sewage has remained the same, it has been established that problems are due mainly to the quality of industrial effluent. The effectiveness, thrift and margin of Darvill W W W will be estimated in order to establish the impacts of treating industrial and domestic waste water over the period 1993-1996. The SDR method looks at Darvill W W W as a service providing institution in the context of an environment that is affected by both human/social and development components. The systems approach examines the interaction between the Works (social institution) and its environment.

Wet Effluent comprises of liquid effluent, specifically effluent that is disposed of through the sewers and can be distinguished from solid waste.

Important national water quality standards as laid down by the Department of Water Affairs and Forestry (DWAF) are used in the SDR analysis. Economic indicators of capital, labour, energy and chemical costs are also incorporated in the study. The quality of treated water is investigated in terms of indicators including *E.coli*, Soluble Reactive Phosphate, Total Suspended Solids, Chlorine and Ammonia. The ecological impacts and consequences of trends in these indicators are analysed as are economic trends in the costs of treating waste water to acceptable levels.

The second part of this study outlines a framework for solving ineffective methods of wet industrial effluent disposal from the vegetable oil industries in Pietermaritzburg. This is the cause of major problems to the operating capacity of Darvill WWW. Due to the lack of effective control and monitoring, industries are allowed to discharge effluent of poor quality to the city sewers. Both local By laws and national laws are not effective in regulating discharge to sewers. The industrial effluent tariff which is set by the council appears to favour industries as ratepayers subsidise clean up costs. The current situation therefore tends to ignore the principle of the polluter pays. This principle is rapidly gathering international acceptance as more countries become involved in pollution prevention but it is not being applied in Pietermaritzburg with regard to effluent disposal. Darvill WWW has recently been plagued with problems caused by high concentrations of soap, oil and grease (SOG) and the vegetable oil industry has been isolated as the major contributor of SOG. Regular monitoring of these industries has produced evidence that indicates that they are polluting the sewers. They have also been found guilty of illegal dumping into rivers. National legislation prohibits the pollution of rivers, lakes and streams.

Proposed management options investigate the involvement of interested and affected parties and proposed solutions to some of the problems that are experienced. Included in the management plan is the involvement of UW as the owners of Darvill WWW, the Pietermaritzburg City Council and its regulation using the industrial effluent tariff and drainage By-laws and regulation and control by DWAF. Alternate methods of regulation are investigated. These include the option of clean technology, enforcing the "Polluter Pays" principle and regulation through economic incentives.

Chapter one gives a literature review of aspects of sustainable development and environmental indicators with reference to SDR. The SDR model is outlined and its use as indicators of sustainable development and the environment is discussed. This is followed by an ecological and economic analysis of Darvill WWW in Chapter two. Trends in SDR indicators are presented and analysed for the Works during the period 1993-1996. Management options for the disposal of wet industrial effluent from the vegetable oil industries are discussed in Chapter three. Current regulation of wet industrial effluent in Pietermaritzburg is investigated and alternate methods are discussed. Finally the implications of using SDR indicators to assess the ecological and economic aspects of Darvill WWW and proposed options for regulating wet industrial effluent disposal in Pietermaritzburg are discussed in the Conclusion.

CHAPTER ONE

LITERATURE REVIEW

1.1 ASPECTS OF SUSTAINABLE DEVELOPMENT AND ENVIRONMENTAL INDICATORS WITH REFERENCE TO SUSTAINABLE DEVELOPMENT RECORDS.

It is difficult to find a single definition of sustainable development and various specialists give a variety of definitions. Barbier and Markandya (1993) suggest two interpretations of this concept; the wider concept that is concerned with sustainable, economic, ecological and social development and the more narrowly defined concept largely concerned with environmentally sustainable development which is optimal resource use and environmental management over time.

Braat et al, (1991) seems to agree that sustainable development is a combination of two basic notions, namely economic development and ecological sustainability. Early environmentalists failed to present their concerns as economic as well as ecological issues. Ecologically sustainable economic development can be thought of as the process of related changes of structure, organization and activity of an economic-ecological system, directed towards maximum welfare which can be sustained by the resources to which the system has access. Sustainable development according to Hammond et al, (1995) involves the interaction of economic, social and environmental factors. It is for all nations, rich, poor, industrialized, agricultural, urban and rural. This therefore highlights the need for a social dimension to be included in the definition of sustainable development.

Figure 1 emphasises that the environment maintains a relationship between human activity, the economy and ecosystems. Resources provide an input into the economy where a two way relationship with people exists. The result is an impact on the people, the encroachment on ecosystems and ecosystem services and the generation of waste and pollution.

The underlying concept of sustainable development represents an attempt to reconcile or establish a balance among economic, social, and environmental factors. As part of the efforts to give the term operational meaning, many proposals for indicators of sustainable development have emerged since the 1992 Earth Summit on Environment and Development. Delegates at the summit agreed that a sustainable overall framework must link the environment with both economic and human development. Since the United Nations Conference on Environment and Development in 1992, sustainability has become a widely shared goal among many internationally recognised organizations (OECD, 1995).

Defining sustainability is difficult, but it is evident that sustainability should not be defined from a purely economic perspective nor a narrow ecological perspective. Both the ecological sustainability and the viability of economic development need to be stressed. According to Holmberg (1991) the time to unite the sciences of economics and ecology has arrived, especially as ecological degradation now threatens to act as a brake on economic development. This does not mean that the social impacts related to sustainable development should be ignored as without emphasising human and societal impacts it will be impossible to attempt to define sustainable development.

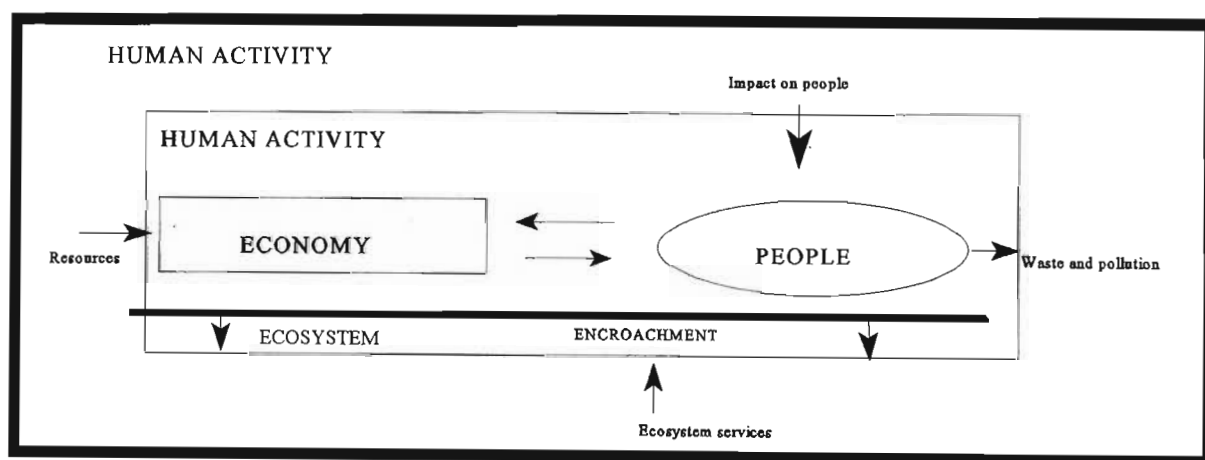


Figure 1 THE SOCIAL IMPACT ON SOME ASPECTS OF SUSTAINABLE DEVELOPMENT Source: Hammond *et al.*(1995)

The concept of sustainability should also refer to the sustainable relationship between society and the environment. Sustainability is achieved when there is a certain stability or balance between society and the environment and can neither be defined nor measured without relating it to quality standards for society as well as for the environment (Haes *et al*, 1991). Although sustainable development is becoming a key concept and a goal in local and international environmental policies, devices or yard sticks to measure practical policies against are needed. Unless there is some clear measure or at least some indicator of sustainable development, the effectiveness of policies and development structures cannot be adequately assessed (Verbruggen and Kuik, 1991).

The definition of sustainable development includes economic and social development and is also linked to sustainable environment. Hence the human environment is also affected. Aspects of the human environment include natural resources such as air, water and soil. Increasing development includes increased industrialisation and urbanisation, which impacts on our natural resources for example increased pollution. Sustainable development is necessary to promote a long term economic benefit without exacting environmental costs. It is difficult to find a single definition of sustainable development but most definitions highlight the following aspects; an emphasis on the environment, the extension of a time horizon in development decision-making and a greater equity with and between present and future generations.

The well-known Brundlant report defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their needs” (World Commission of Environment and Development, 1997). A measure of sustainable development promotes a need for indicators which should also measure the pressure from society and the environment (pollution and resource use) and indicators for the state of the environment (ecological integrity or bio-diversity). Environmental indicators, unlike sustainability indicators, do not attempt to measure sustainability. They address some of the trends in the environment that can give rise to non-sustainability (Pearce&Warford, 1993).

A sustainable environment requires that all those who make decisions which affect the environment take full responsibility for the impact of those decisions. Sustainable development as stated by Holmberg (1991) is a process and not a condition and there are many different and legitimate ways to go about it. The indicators that are associated with sustainable development do not always provide precise objectives or standards; they are a few trends out of many that one might expect to find in a society that is moving towards sustainable development.

The pursuit of sustainable development requires indicators of success where the definition of sustainability is foremost. If physical indicators are needed, the immediate problem of aggregating diverse indicators occurs. If a definition of sustainability is adopted in which at least, the critical environmental assets do not decline, then physical indicators can be used to assess non-sustainability but this is a remote possibility. This lack of consensus on the exact operational meaning of the concept of sustainable development makes the search for sustainable development indicators more difficult.

1.2 WHAT ARE SUSTAINABLE DEVELOPMENT INDICATORS?

The term indicator in measurement theory is used for the empirical specification of concepts that cannot be fully operationalised on the basis of generally accepted rules. Indicators are a compromise between scientific accuracy and the demand for concise information. More specifically indicators may be used for two purposes:

- 1) Planning: problem identification, allocation of socio-economic resources and policy assessments and
- 2) Communication: notification, warning, mobilization and legitimisation of policy measures (Verbruggen and Kuik, 1991).

Indicators are not an end in themselves but rather they are tools that can build support for needed change if they are used with wisdom and restraint. An indicator is something that provides a clue to a matter of large significance or makes perceptible a trend or phenomenon that is not immediately detectable.

Indicators imply a scale against which some aspects of public policy issues such as policy performance can be measured. Indicators provide guidance, needs, priorities and trends in policy effectiveness. An indicator must reflect changes over a period of time with regard to a specific problem. It must be reliable and reproducible and wherever possible it should be calibrated in the same terms as the policy goals or targets to it (Hammond *et al*, 1995).

Sustainable indicators reflect the degree to which human needs including the need for a safe, healthy and productive environment are met. Measures of environmental impacts on human health and welfare are important to sustainability either as environmental indicators or as components of social indicators. Of equal importance is the degree to which exposure to pollution or access to clean water and clean air vary among social and economic conditions (Hammond *et al*, 1995).

Environmental indicators can be defined as quantitative descriptions of changes in either anthropogenic environmental pressure or in the state of the environment. This therefore gives rise to pressure indicators and environmental indicators. Environmental pressure indicators express the amounts and levels of emissions, discharges and depositions in a predetermined region. The pressures exerted by society on the environment are commonly categorised as; pollution which entails the introduction into the environment of substances or energy residuals that may have a negative impact over exploitation of resources, landscape, ecosystems and organisms modification (Verbruggen and Kuik, 1991).

Sustainability indicators can be defined as indicators which provide information, directly or indirectly, about the future sustainability of specified levels of social objectives such as material welfare and environmental quality. Two types of sustainability indicators have been distinguished by Braat (1991); the predictive indicator which provides direct information about the development of a relevant socio-economic and environmental variable, which constitutes the basis for anticipatory planning and management; and the retro specific indicator which includes traditional policy evaluation and historical trend indicators that provide information about effectiveness of existing policies or about autonomous developments, respectively. Retro specific indicators may provide information about future sustainability. The study of Darvill WWT uses standards that were proposed by DWAF in 1963, based on what is perceived to be acceptable levels of pollution.

Indicators would have to be derived from the specific characteristics of the environment and the economy. Efficiency and equity are also important dimensions to be included in the development of indicators as is integrity and manageability. In this study on waste water treatment, water quality indicators are used specifically to analyse the efficiency of the waste water treatment processes at Darvill WWT.

Sustainable Development indicators are required with a scope wide enough to reflect:

- a) the factual developments in the use of environmental resources, including the environmental impacts of economic activities and environmental management and the change of environmental capital or the state of the environment, and
- b) the potential for management towards sustainability, which would require current or anticipated development in science and technology in terms of environmentally relevant products, processes and inputs and the development of managerial tools such as appropriate institutions for environmental resource management, policy instruments and budgets.

1.3 WHY DO WE NEED SUSTAINABLE DEVELOPMENT INDICATORS?

It is obvious that some people in every society wish to have a high quality environment and that some people are willing to spend a great deal of time and effort to attain and maintain such an environment. Therefore it is necessary to extensively support the proposition that a high quality environment could be an important policy objective in every society. If a high quality environment is to be pursued by a society, it is necessary to find ways of measuring and operationalizing these concepts to ascertain to what extent the society is successful in achieving its policy objectives (UNESCO, 1978). This points to a need for reliable indicators.

The impact of pollution is important locally as well as globally. On a global scale many industrial countries including those in Eastern Europe, provide experiences that illustrate the economic costs of pollution. In the developing world water pollution and water management receive a great deal of attention primarily because water has such an impact on the health of the population (Pearce & Warford, 1993). South Africa is characterised by a lack of available information and adequate indicators of the current water pollution situation.

A certain amount of environmental information is required to show the state of the environment. Indicators provide information to mediate between reality and policy. Since these purposes will usually be complex and perhaps conflicting, there are frequent debates over indicators, motivated by debates over policies and perhaps serving as surrogates for them (ISIE, 1990).

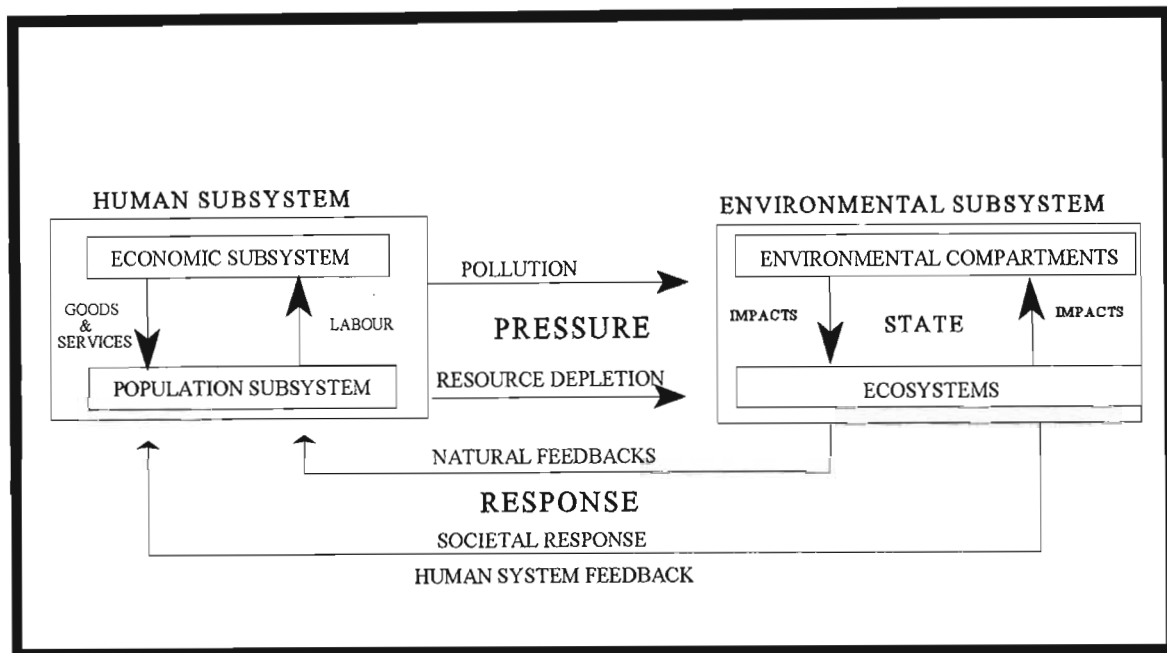


Figure 2 THE PRESSURE-STATE-RESPONSE MODEL

Source: Hammond *et al*, (1995)

According to the framework for Pressure, State and Response indicators (PSR) in figure 2 environmental indicators arise from a simple set of questions namely, what is happening to the state of the environment and why is it happening (Hammond *et al*, 1995)?

State indicators measure the quality or state of the environment while pressure indicators show the causes of environmental problems and response indicators gauge the efforts taken by society or a given institution to improve the environment or mitigate degradation. The PSR model is used extensively in determining the state of environment. The PSR framework is based on a concept of causality (human activities extend pressures on the environment and change its quality of natural resources (state response) while society responds to these changes through environmental, general economic and sectoral policies (the societal response).

While the PSR framework has the advantage of highlighting these links, it tends to suggest a linear relationship in the human-activity-environment interaction (see figure 3). This should not obstruct the view of more complex relationships in ecosystems and the environment-economy interactions (OECD, 1995).

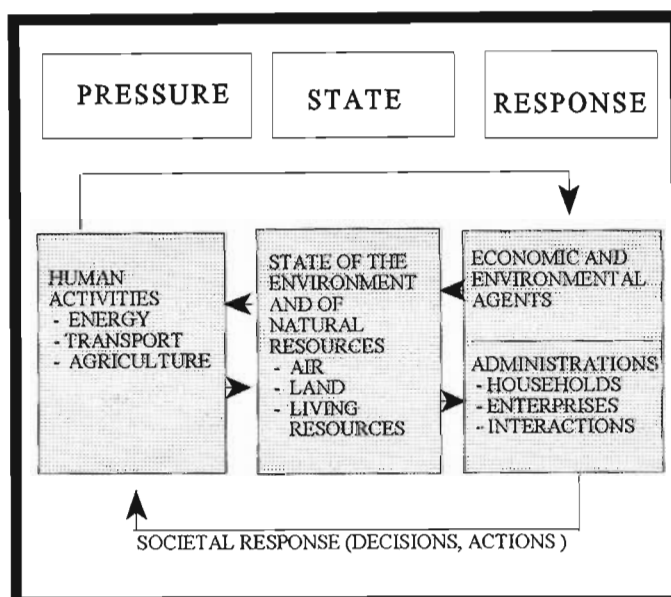


Figure 3 INTERACTIONS OF THE PSR MODEL
Source: OECD (1995)

An interest in sustainable development and growing public concern about environmental threats have stimulated governments to re-examine their capacity to assess and monitor the state of the environment and detect changing conditions and trends. Pressures are also growing for the accurate measurement of performance or the evaluation of how well governments are doing in their efforts to influence their domestic environmental policies and international commitments.

Thus environmental indicators are becoming increasingly seen as necessary tools for helping to chart and track the course towards a sustainable future (OECD, 1995). The goal of environmental indicators is to communicate information about the environment and about human activities that effect it in ways that highlight emerging problems and draw attention to the effectiveness of current policies.

1.4 PROGRESS IN THE DEVELOPMENT OF SUSTAINABLE DEVELOPMENT INDICATORS

The approach of attaching economic value to environmental costs was established as early as 1972 by the OECD countries, when they adopted the “Polluter Pays” principle. It holds that the costs to society of pollution or pollution control should be internalized in the costs of the polluting goods or services. But after almost 20 years the principle has yet to be widely implemented (Holmberg, 1991).

Although studies indicate that Dutch and Swedish policy makers have initiated the development of social development indicators, this is a relatively new field that requires further investigation. Many highly aggregated economic and social indicators have been widely adapted but there are virtually no comparable national environmental indicators to help decision makers or the public to evaluate environmental trends. The definition of sustainable ecosystems refers to the interdependent system of abiotic and biotic components. In Sweden this ecological approach with regard to sustainable ecosystems has been used extensively in frameworks such as the National Policy Document on Water Management, Ministry of Transport and Public Works. This policy has resulted in an eco-distinctive classification and mapping which has served as a geographical basis for Dutch documents such as the National Environmental Survey (Haes *et al*, 1991).

Other organizations conducting studies in this field include the Canadian government, the United Nations Commission on Sustainable Development and the United States government. Hammond *et al*, (1995) argue that environmental indicators are the best place to start developing sustainable development indicators. Although economic and social indicators already influence policy and decision making, an unambiguous set of signals on the effects of human activities on the environment is missing.

Environmental indicators in democratic countries have significant use as the electorate pushes the government to create and maintain environmental indicators that the public find easy to grasp. This may be the surest way to compel the government to attend to the environment. Besides illustrating environmental trends, indicators can be designed to measure how well or how poorly policies work, thereby also pointing the way to better approaches (Hammond *et al*, 1995).

In South Africa little work on such indicators of pollution matters is available. Although there are local air and water quality indicators or indices of one kind or another in use in some industrial countries including South Africa, only a handful of indicators is widely adopted and systematically reported. Even the environmental indicators that are developed and compiled by the OECD are not routinely and publicly reported. Hammond *et al*, (1995) suggest that indicators based on conventional data will not capture many environmental issues which are important to sustainable development hence the need for additional environmental indicators and for more highly aggregated measures.

1.5 SUSTAINABLE DEVELOPMENT RECORDS AS INDICATORS

The SDR method of indicators uses the systems approach to analyse the relationship and interactions between social institutions and their environment. SDR can be used as the social science framework to study the use of representative indicators of impacts on the environment through performance measurements or indicators. This approach is the product of strategic business management, where the business firm is used as an implicit metaphor for understanding the development of a society (Bergstrom and Nilsson, 1995).

1.5.1 THE SDR MODEL

The main focus of a study using SDR is to look at how social institutions interact with their environment, to better understand the behaviour of social institutions towards the environment, to determine whether or not the social institutions are achieving their aims and to explain certain trends that are evident. SDRs will be used with these principles to analyse the efficiency of the Darvill WWW in Pietermaritzburg. The waste water plant represents a social institution. Material and energy flows are used as representative indicators of impacts on the environmental systems. This is important in the Darvill WWW analysis as a result of the involvement of water and waste as important components of resource management. The SDR model has three parts: resource base, system and service (see figure 4). The resource base consists of the ecosystems, financial resources and knowledge. All these components are needed to support and run the social institution. The system consists of the fixed capital assets and operation of a given social institution and the service is the product of the system.

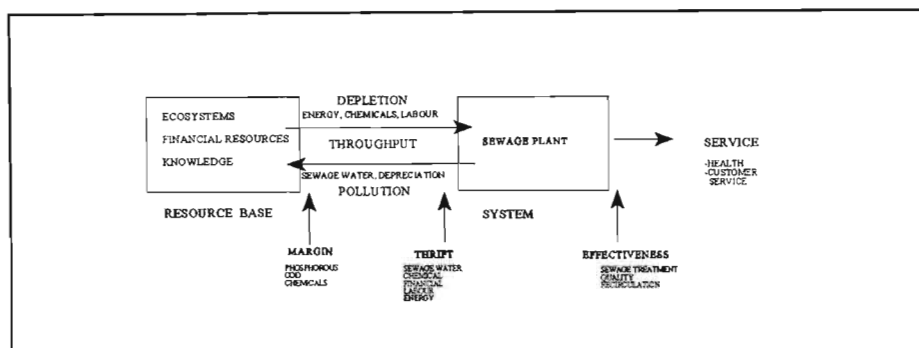


Figure 4 THE RELATIONSHIP BETWEEN THE SDR MODEL AND SDR KEY INDICATORS

Source: Bergstrom and Nilsson, 1995

1.5.2 SDR KEY INDICATORS

The first characteristic of an SDR key indicator is that it should be constructed as a quotient, with a numerator in accordance with the economic logic of the SDR analysis. Second, all measurements should be (within limits) independent of scale. For example, the same measurement of performance can be used for assessing a section of the social institution as well as for the whole institution. It can be anticipated that these types of standard measurements will develop into values based on experience which will facilitate the practical interpretation. There are five leading principles for the choice of SDR key indicators (Bergstrom and Nilsson, 1995):

- The *non violence principle* states that using fewer resources is better or preferred. Consequently, a key indicator should show that little effort is needed to achieve one's objective. This is the basic economical reasoning.
- The *theory principle* states that all questions and answers should be rigorously formulated in theoretical terms before looking for empirical indicators. Hypotheses and conclusions can be related to the general SDR model structure, and relatively poor data (which for example is easily available and inexpensive to use) can be used without distorting the clarity of thinking. Essential to the theory principle is that thoughts should never be limited by the data sources.
- The *"hit-the-board" principle* states that rough and relevant is preferable to precise and inexpedient. To hit the board is enough; to hit the bullseye requires too much effort.

- The “*cluster*” *principle* derives from the hit-the-board principle. If very reliable information is needed and the available indicators are perceived as too rough, it is better to design a cluster of rough indicators than a single perfect one. A cluster of indicators consists of independent measurements. If all the indicators in a cluster give the same signal, it can normally be considered as reliable information.
- The “*salami*” *principle* says that it is wise to distinguish among the effectiveness, thrift, and margin aspects of the SDR method (figure 5):
 1. Effectiveness refers to how effective or appropriate the services provided by the system.
 2. Thrift refers to whether the system requires a modest input of resources and energy. Minimizing thrift measurements is usually associated with a more effective resource usage. In the SDR analysis however, the economical format is emphasized, suggesting that a ratio with a higher number is better than a lower number. Suppose that two different social institutions A and B, render the same type of service but the inflow of material resources and energy for A is much higher than that for B. Therefore B is thriftier or the performance measurement *thrift* of B is higher than the one for A.
 3. Margin refers to whether the inflows and outflows can be sustainably maintained without impairing the resource base and essential ecological functions.

The SDR indicators allow for various activities, transformations and states which are correlated and expressed in various units. It is also desirable to be able to compare between the current state and the desired state.

1.5.3 INDICATORS FROM PAST RESEARCH

Four desirable features of indicators have been found in previous research, they include representing the chosen system and having a scientific basis, being quantifiable, clearly indicating part of the cause-effect chain and offering implications for policy. The first two features can be ascribed to most of the SDR indicators.

However an SDR analysis makes use of indirect measurements, with a more vague scientific status but supposedly correlated with other measurements of appropriate scientific status. Some SDR indicators focus more on the context of the cause - effect chain than on a specific part of the actual chain.

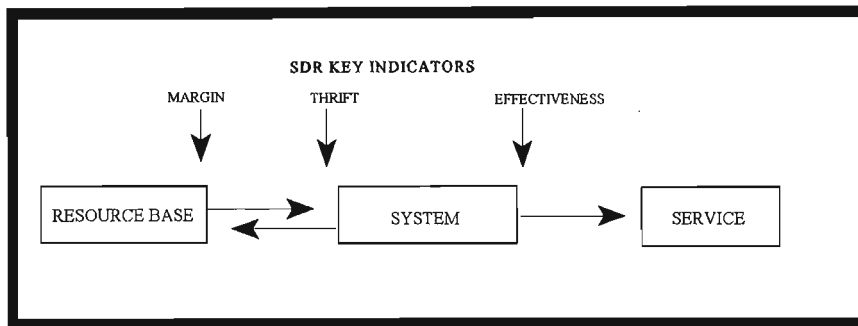


Figure 5 ASPECTS AND INDICATORS OF THE SDR MODEL Source: Bergstrom and Nilsson, (1995)

The fourth feature is partly applicable to the SDR system in this study as management at Darvill WWW are not the only authorities who are responsible for policy making. However trends in SDRs which do not highlight problems can make it necessary to revise SDR indicators (Verbruggen and Kuik, 1991).

1.5.3.1 THE SDR MODEL IN COMPARISON TO A SIMILAR MODEL PROPOSED BY HOLMBERG AND KARLSSON

There are close similarities between the model that has been proposed by Holmberg and Karlsson (1992) and the SDR method as is evident from Table 1. The SDR approach facilitates the discussion of the relationship between the size of the system and the resource use of the system. The capital and operation of the system is typically the object of decision-making and the indicators, relating performance to the system must be of practical use.

Holmberg and Karlsson do not describe how different indicators or sets of indicators might be assessed together. By comparison, the SDR approach has three categories of indicators (effectiveness, thrift and margin) which focus on different aspects of system performance.

According to Holmberg and Karlsson, the value of the indicator (p) is equivalent to service related to the physical flow (P):

$$p = \text{service} / P \dots\dots\dots 1$$

In the SDR method this relationship is separated into two different ratios:

1 The effectiveness indicator (e) is equivalent to service in relation to the size of the system (A):

$$e = \text{service} / A \dots\dots\dots 2$$

2. The thrift indicator (t) is equivalent to the size of the system (A) as related to the inflows required and the outflows generated by the system (P):

$$t = A / P \dots\dots\dots 3$$

According to Holmberg and Karlsson it is desirable to normalize socio-ecological indicators in such a way so that they become dimensionless. This differs from the system of SDR indicators as the information content of the indicators tends to decrease.

TABLE 1: COMPARISON OF THE BASIC ELEMENTS OF SDR AND HOLMBERG AND KARLSSON MODELS

ASPECT	SDR	HOLMBERG & KARLSSON
Support/ prerequisite	Resource base(including knowledge, natural and financial resources)	Nature
Supported unit	System (capital and operation	Technosphere
Yield	Service	Service
Focus of analyses	Effectiveness, Thrift, Margin	Societal influence on nature and transformations in the technosphere yielding services to the human sphere

Source: Adapted from Bergstrom and Nilsson (1995)

CHAPTER TWO

ECOLOGICAL AND ECONOMIC ANALYSIS OF DARVILL WASTE WATER WORKS

2.1 BACKGROUND

Darvill WWW is located east of Pietermaritzburg approximately 7 km from the City centre. The effective ownership and responsibility for the operation of the Works was taken over by UW from the City of Pietermaritzburg in May 1992. It has recently been upgraded at a cost of R36 million, with the objective of achieving full compliance with national effluent quality standards and to increase capacity to cope with peak flows. At Darvill WWW minimal use is made of chemicals in the purification process as the plant relies heavily on biological processes.

Darvill WWW serves the greater Pietermaritzburg area and is responsible for the treatment of both domestic and industrial effluent. On average each person produces between 80 and 250 litres of wastewater per day which eventually arrives at the Works for treatment via the sewer outfall. Due to the various industries in the area, industrial effluent has a tremendous mixture of components. The main purpose of wastewater treatment is to cleanse wastewater with a view to safely return it to rivers. Wastewater works provide a vital service in that they assist in combatting water pollution and the spread of diseases and viruses which cause illness.

Illegal industrial discharges into the sewer system have a detrimental effect on the biological phosphate removal process used at Darvill WWW. Industrial discharges, such as oily and sticky waste products (soap and by-products of margarine manufacture) in particular have been identified as the cause of some problems. Processes at the Works are affected as a result of poor settleability of sludge particles, this results in the surface of tanks being clogged and subsequent treatment processes are affected. As a result the final effluent that is discharged to rivers can fail to meet the required standards. The SDR method of social indicators outlined in Chapter one is used to analyse the performance of Darvill WWW.

Darvill WWW is studied as a social (service providing) institution interacting with the natural and

Darvill WWT is studied as a social (service providing) institution interacting with the natural and social environment. Darvill WWT management has noticed that the quality of certain industrial effluents is affecting the operation of the works. The aim of this study is to ascertain the extent and associated impacts of these problems using the systems approach of SDRs.

According to the SDR method the plant is defined as a system (capital and operations) separate from the resource base on which it is dependant. The resource base consists of ecosystems, financial resources and knowledge. This resource base is a prerequisite for the long-term existence and proper functioning of the plant. The SDR indicators of effectiveness, thrift and margin are used to describe the functioning of the system/plant. Figure 6 depicts Darvill WWT as outlined according to SDR principles while section 2.2 describes the SDR model of Darvill WWT in more detail.

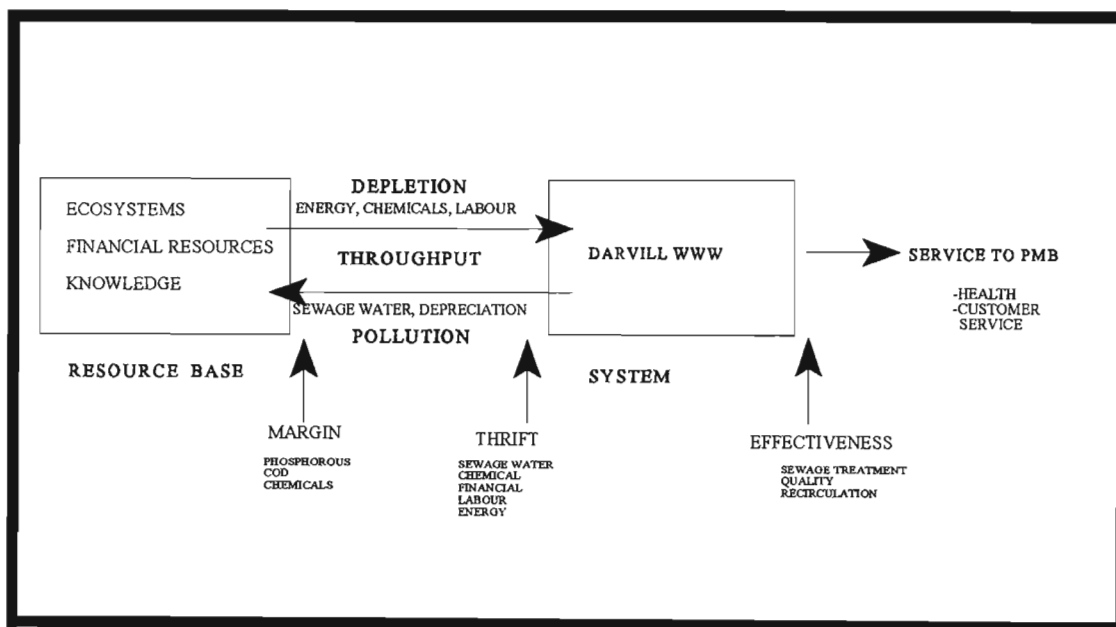


Figure 6 A MODEL OF DARVILL WWT AS DEPICTED BY SDR

Source: Bergstrom and Nilsson, 1995

2.2 THE SDR MODEL FOR A WASTE WATER PLANT

The specifications of different variables describing service, system (capital and operations), withdrawal of resources, release of waste products, and the resource base of Darvill WWT is listed in Table 2.

TABLE 2 : DARVILL WWW EXPRESSED IN THE SDR METHOD

SERVICE	
1.	Water of high quality
2.	Operational disturbances
3.	Customer services
SYSTEM	
1.	Registered value of assets
2.	Infrastructure and Equipment
3.	Size and space needed for the system
WITHDRAWAL OF RESOURCES FROM RESOURCE BASE	
1.	Energy
2.	Materials and Chemicals
3.	Water
4.	Finances
5.	Labour
EMISSION OF WASTE PRODUCTS INTO THE ENVIRONMENT	
1.	Sewage
2.	Sludge
3.	Heat
4.	Chemicals
RESOURCE BASE	
1.	Ecosystems
2.	Financial resources
3.	Knowledge

Source: Bergstrom and Nilsson (1995)

2.2.1 INDICATORS OF THE SDR METHOD WITH RESPECT TO DARVILL WASTEWATER WORKS

Following the SDR model given in Chapter one, effectiveness, thrift and margin are key indicators for the analysis of Darvill WWW. Effectiveness (appropriateness of the services that is provided by Darvill WWW) indicates the abilities of the treatment processes being carried out. This measures whether or not the treatment processes are effectively treating wastewater to national standards and hence gives relevant information to determine the impacts on society and the environment. Examples of services that we need and value are health, environmental quality, recirculation of water and nutrients. Variables used, for the study reflect water quality recirculation and recirculation of nutrients:

Water quality is analysed using *E.coli*, Chlorine, Soluble Reactive Phosphate (SRP), Total Suspended Solids (TSS), Conductivity, Chemical Oxygen Demand (COD) and Ammonia, variables that are also used nationally to determine water quality. Those samples which do not achieve 100% compliance (the number of samples that do not comply with the required national standard divided by the total number of samples taken) are investigated. Appendix A1 gives a list of the national standards as laid out by DWAF. Relevant data will be analysed during 1993-1996 to determine observable trends (see Tables 5-7). The recirculation of nutrients is measured according to the amount of sludge that is recycled.

Thrift (input of materials and resources relevant to output) is measured as the quota between some indicator of the size/ capacity of the plant and the resource expenditure (eg water, money, chemicals etc.). Variables chosen to measure thrift include chemical, financial, labour and energy costs. Each variable measures thrift in terms of kilolitres of dry weather effluent treated thereby investigating the economics of treating wastewater. Dry weather inflow is measured according to incoming effluent for the drier months of June, July and August. This is based on the assumption that the storm water component of sewage inflow is negligible and all incoming sewage is either domestic or industrial effluent.

Financial thrift is measured according to the depreciation of initial and additional capital required to operate Darvill WWW in relation to the total dry weather inflow (rands of depreciation per kilolitre of influent). Since UW still has outstanding loans on Darvill WWW, instead of calculating depreciation of assets, redemption of loans is measured. Therefore financial thrift was determined on interest and redemption and not on depreciation. Chemical thrift is defined as the ratio between the total cost of chemicals consumed by the plant and the total dry weather inflow (rands of chemicals consumed per kilolitre of influent). Labour thrift is measured by the ratio between the labour required to operate the Works and the total dry weather inflow (hours of labour per year per kilolitre of influent). Energy thrift is the ratio between the total cost of energy to operate the Works and the total dry weather inflow (rands of energy consumed per kilolitre of influent).

The Darvill WWW margin questions whether the resource base can provide the inflows and assimilate the outflows. Since the level of sustainable human impact on the ecosystem is difficult to assess, it is necessary to come up with some reasonable estimates. A minimal level set by the government (sewage treatment standards or water discharge standards) may or may not reach the long-term sustainable objectives, but it could be used as a tentative margin indicator. Margin is a normative measure between the current state and some reference position which is taken as the national water quality standards that are given by DWAF. Water Quality is analysed according to those variables that do not meet 100% compliance. The actual range of results is compared to the standard range of results as stipulated by DWAF. The number of samples below and above the standard range is used to indicate the marginal difference from the standard. The aim of this indicator is to establish the actual deviation from required standards. Chemical margin is shown by the relationship between the value of the sludge and the cost of chemicals therefore the marginal cost of producing sludge is measured. Since Darvill WWW relies heavily on biological processes of waste water treatment, this indicator is not a complete measure of chemical margin.

Table 3 summarizes the set of key indicators (effectiveness, thrift and margin) to be derived for Darvill WWW, following the SDR model. For each indicator, the numerator and denominator is defined to show how they will be estimated in section 2.3.

TABLE 3 : A set of key indicators for Darvill WWW using SDR indicators

KEY INDICATORS	NUMERATOR	DENOMINATOR
EFFECTIVENESS		
QUALITY OF WATER <i>E. coli</i>	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
PHOSPHOROUS	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
C.O.D.	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
CHLORINE	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
TSS	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
COLOUR	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
AMMONIA	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
CONDUCTIVITY	SAMPLES COMPLYING	TOTAL NUMBER OF SAMPLES
RECIRCULATION OF NUTRIENTS	AMOUNT OF SLUDGE USED	AMOUNT OF SLUDGE PRODUCED
THRIFT		
WATER TREATMENT	VOLUME OF WATER DISCHARGED	VOLUME OF INFLUENT
FINANCIAL	VOLUME OF DRY INFLUENT	CAPITAL
LABOUR	VOLUME OF DRY INFLUENT	LABOUR
ENERGY	VOLUME OF DRY INFLUENT	ENERGY ON PLANT
CHEMICALS	VOLUME OF DRY INFLUENT	CHEMICALS USED
MARGIN		
<i>E.coli</i>	ACTUAL RANGE	STANDARD RANGE
PHOSPHOROUS	ACTUAL RANGE	STANDARD RANGE
C.O.D.	ACTUAL RANGE	STANDARD RANGE
CHLORINE	ACTUAL RANGE	STANDARD RANGE
TSS	ACTUAL RANGE	STANDARD RANGE
COLOUR	ACTUAL RANGE	STANDARD RANGE
AMMONIA	ACTUAL RANGE	STANDARD RANGE
CONDUCTIVITY	ACTUAL RANGE	STANDARD RANGE
CHEMICALS	VALUE OF SLUDGE	COST OF CHEMICALS

2.3 ANALYSIS AND DISCUSSION OF RESULTS

Data provided by Umgeni Water (1996) for the period 1993 to 1996 were analysed for Darvill WWWW according to key indicators in Table 3. Table 4 illustrates trends in these indicators at Darvill WWWW during this period. Table 5-7 illustrates analysis of data on an annual basis.

The data in Table 4 show annual trends from March 1993 to February 1996 (each annual financial period extends from March to February). Data include nominal registered value; size; depreciation and capital of the Works; energy, water and chemicals consumed by the plant, cost of manpower and number of people served by Darvill WWWW and volume of influent, sludge and treated water discharged. Compliance data are also indicated for *E. coli*, Chlorine (Cl), Soluble Reactive Phosphate (SRP), Total Suspended Solids (TSS), Conductivity (COND), Chemical Oxygen Demand (COD), and Ammonia(NH₃).

The nominal registered asset value of the Works increased from R50 million during 1993-1994 to R 68,5 million during 1994-1995 and R87 million during 1995-1996. Reasons for increasing asset value include extensions and upgrading of existing plant assets. Despite upgrading, the size of the Works has remained constant at 55 hectares during the period of study. A large portion of approximately 50 hectares is used as a sludge farm.

As UW still has an outstanding loan on Darvill WWWW, interest and redemption is calculated instead of depreciation. The trend during 1993-1996 indicates that interest and redemption increased from R7 596 000 to R 9 660 000. Capital costs include initial purchase as well as additional costs, and increased markedly from R 8, 296 x 10⁶ during 1993-1994 to R 11, 042 x 10⁶ during 1995-1996. Additional capital costs include costs of renovations required for ensuring that the Works can cope with increasing quantity and decreasing quality of influent.

Energy consumed increased drastically from 6 006 383 kWh during 1993-1994 to 14 682 420 kWh during 1995-1996. In comparison chemical costs during this period decreased from R1 703 982 to R 1 051 560. This is due to changes in the treatment processes.

With increased extensions and improvements, the Works is relying more on the biological process of phosphate removal which demands greater energy consumption. Further investigations are required to determine whether it is more viable to use the biological method of treatment or the chemical treatment process.

The number of people employed by Darvill WWT decreased from 42 full time employees during 1993-1994 to 34 during 1995-1996. Consequently the number of labour hours decreased but this does not correspond with the marked increase in the cost of manpower. Manpower expenses increased from R 452 700 during 1993-1994 to R 1 739 700 during 1995-1996. This discrepancy is attributed to the increasing use of casual labour which is favoured over permanent labour because there is less threat of human resource problems such as strikes and union problems. Management is not responsible for perks and benefits including medical aid and pension schemes for casual labourers. The exact number of casual labourers employed at the Works is unknown since UW makes use of a contractor.

Maintenance costs on the plant also increased during the period of study. This has been linked to management problems associated with the deteriorating quality of industrial effluent. Vegetable oil industries have been sited as the contributors to increasing levels of SOG which has a detrimental effect on the operation of the Works. Oil and grease clogs up the plant and affects the operation of the settling tanks and anaerobic and aerobic digestion processes. As a result plant equipment and machinery needs to be regularly cleaned out, thus increasing maintenance and labour costs. The cost/benefit ratio of operating the Works is also affected, as costs increase in order to maintain national and local standards of treated water. Five vegetable oil industries have been isolated as the cause of SOG problems at the Works.

As industrial development in Pietermaritzburg is relatively slow, these industries are responsible for a substantial contribution to the economy of the city. This is difficult to assess most of the

goods that they produce are for export. The manufacturing processes used by these industries are very mechanical and are not very labour intensive, but these industries do provide employment opportunities.

It may be that these industries are allowed by the Council to pollute the environment in order to secure their contribution to the economy. There six vegetable oil industries in Pietermaritzburg and these industries possess differing attitudes to the pollution problems. Their respective input into the City's economy differs but as a single industry they are a large contributor to the overall economy of the City.

The volume of freshwater being consumed in the City increased from 23 894 054 kl during 1993-1994 to 25 393 828 kl during 1995-1996 probably due to population expansion and increased industrialisation. Influent has also increased from 16 655 913 kl during 1993-1994 to 18 487 743 kl during 1995-1996. Consequently, sludge volumes and the volume of treated water being discharged to the river also increased. Compliance data for the discharged treated water varies. Actual samples of treated water were compared against the standards laid out by DWAF (see appendix A). Increasing non-compliance with *E. coli* results appear to be the greatest cause for concern while the other variables produce varying results. Compliance data of variables such as Chlorine show increasing compliance during the three-year period. Increasing compliance of Chlorine and TSS may be attributed to improved treatment processes and increased renovations. The large injection of capital into the Works has helped improve compliance with some national standards. However, other variables indicate fluctuating levels of compliance. Industrial effluent of poor quality appears to be one of the main causes for this.

TABLE 4: RELEVANT DATA FOR DARVILL WWW FROM 1993-1996

	1993-1994	1994-1995	1995-1996
NOMINAL REGISTERED ASSET VALUE	R 50 MILLION	R68.5 MILLION	R 87 MILLION
SIZE AND CAPACITY	Plant 5 ha, Sludge farms 50 ha	Plant 5 ha, Sludge farms 50 ha	Plant 5 ha, Sludge farms 50 ha
INTEREST AND REDEMPTION	R 7 596 000	R 7 596 200	R 9 660 000
CAPITAL (INITIAL PURCHASE + ADDITIONAL)	R 8,296 x10⁶	R 10,212 x10⁶	R 11,042 x10⁶
ENERGY CONSUMED	6 006 383 kWh	8 815 212 kWh	14 683 420 kWh
WATER CONSUMED	5 074 m³	4 707 m³	3 000 m³
TOTAL COST OF CHEMICALS	R 1 703 982	R 1 070 581	R 1 051 560
UNIT CHEMICAL COST	5.16 c/kl	3.41 c/kl	3.10c/kl
NO. OF PEOPLE EMPLOYED	42 full time	38 full time	34 full time
NO. OF HOURS OF LABOUR	107 224 hrs/yr	107 224 hrs/yr	106 706 hrs/yr
NO. OF PEOPLE SERVED BY THE PLANT	domestic households = 193 816 + industries = 430	domestic households = 200 706 + industries = 446	domestic = 210 450 + industries = 457
COST OF MANPOWER	R 1 452 700	R 1 703 000	R 1 739 700
MAINTENANCE	R 1 822 500	R 2 114 600	R 2 817 600
VOLUME OF WATER SOLD/ CONSUMED	23 894 054 kl	24 785 473 kl	25 393 828 kl
VOLUME OF INFLUENT	16 655 913 kl	17 958 666 kl	18 487 743 kl
VOLUME OF SLUDGE PRODUCED	40 612.5 kl	54 150 kl	57 000 kl
VOLUME OF SLUDGE USED	NONE	NONE	NONE
VOLUME OF TREATED WATER DISCHARGED	15 101 934 kl	16 475 017 kl	18 075 195 kl
NO. OF SAMPLES TAKEN	E coli 233; CI 219; COND 50; SRP 50; TSS 50; COD 50, NH, 50	E coli 255; CI 246; COND 48; SRP 74; TSS 74; COD 74, NH, 74	E coli 161; CI 367; COND 52; SRP 120; TSS 120; COD 120, NH, 120
NO. OF SAMPLES COMPLYING WITH STANDARDS	E coli 214; CI 6; COND 49; SRP 46; TSS 44; COD 50, NH, 50	E coli 217; CI 52; COND 47 ; SRP 65; TSS 67; COD 71, NH, 70	E coli 134; CI 175; COND 51; SRP 120; TSS 95; COD 120, NH, 110
% COMPLIANCE	E coli 92; CI 3; COND 98; SRP 92; TSS 88; COD 100; NH, 100	E coli 85; CI 21; COND 98; SRP 87; TSS 90; COD 95; NH, 94	E coli 83; CI 47; COND 98; SRP 100; TSS 95; COD 100 NH, 92

TABLE 5 : Analysis of data for Darvill WWW using key indicators for the financial period 1993-1994

KEY INDICATORS	NUMERATOR	DENOMINATOR	RESULT
EFFECTIVENESS			
QUALITY OF WATER <i>E. coli</i>	214	233	92%
PHOSPHOROUS	46	50	92%
C.O.D.	50	50	100%
CHLORINE	3	219	1.3%
S.S	44	50	88%
AMMONIA	50	50	100%
CONDUCTIVITY	49	50	98%
RECIRCULATION OF NUTRIENTS	0	40 612.5 kl	0%
THRIFT			
WATER TREATMENT	15 101 934 kl	16 655 913 kl	90.67%
FINANCIAL	16 655 913 kl	R 7 596 000	2.00kl/R/yr
LABOUR	16 655 913 kl	107 224 hrs/yr	155.34kl/hr/yr
ENERGY	16 655 913 kl	R 820 330.42	2.77 kl/kWh/yr
CHEMICALS	16 655 913 kl	R 1 703 982	9.77kl/R/yr
MARGIN			
QUALITY OF WATER <i>E. coli</i>	6 - 287 000Ecoli/100ml	5Ecoli/100ml	SAMPLES BELOW 0 SAMPLES ABOVE 213
PHOSPHOROUS	1 460 - 2 214mg/l	0 - 1000mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 4
C.O.D.	100% COMPLIANCE	0 - 75 mg/l	SAMPLES BELOW NO RESULT SAMPLES ABOVE NO RESULT
CHLORINE	0.15 - 6mg/l	0 - 1 mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 216
S.S	28.0 - 60.2mg/l	0 - 25 mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 6
AMMONIA	100% COMPLIANCE	0 - 10 mg/l	SAMPLES BELOW NO RESULT SAMPLES ABOVE NO RESULT
CONDUCTIVITY	101 mSm ⁻¹	0 - 85 mSm ⁻¹	SAMPLES BELOW 0 SAMPLES ABOVE 1
CHEMICALS	0	R 1 703 982	0

TABLE 6 : Analysis of data for Darvill WWW using key indicators for the financial period 1994-1995

KEY INDICATORS	NUMERATOR	DENOMINATOR	RESULT
EFFECTIVENESS			
QUALITY OF WATER <i>E. coli</i>	217	255	85%
PHOSPHOROUS	65	74	87%
C.O.D	71	74	95%
CHLORINE	52	246	21%
S.S	67	74	90%
AMMONIA	70	74	94%
CONDUCTIVITY	47	48	98%
RECIRCULATION OF NUTRIENTS	0	54 150 kl	0%
THREAT			
WATER TREATMENT	16 475 017 kl	17 958 666 kl	91.74%
FINANCIAL	16 475 017 kl	R 7 596 200	1.75kl/R/yr
LABOUR	16 475 017 kl	107 224 hrs/yr	167.48kl/hr/yr
ENERGY	16 475 017 kl	8 815 212 kWh	2.03kl/kWh/yr
CHEMICALS	16 475 017 kl	R 1 070 581	16.77kl/R
MARGIN			
QUALITY OF WATER <i>E. coli</i>	6 - 224 000Ecoli/100ml 6 - 181 000 Ecoli /100ml	5Ecoli/100ml	SAMPLES BELOW 0 SAMPLES ABOVE 38
PHOSPHOROUS	1 140 - 1 730mg/ml 1 130 - 1 960mg/ml	0 - 1000mg/ml	SAMPLES BELOW 0 SAMPLES ABOVE 9
C.O.D	97.3mg/ml 93.8 - 131mg/ml	0 - 75mg/ml	SAMPLES BELOW 0 SAMPLES ABOVE 3
CHLORINE	0.15 - 2.2mg/ml 0.2 - 2.0mg/ml	0 - 0.1mg/ml	SAMPLES BELOW 0 SAMPLES ABOVE 194
S.S	90.8mg/ml 28.0 - 136mg/ml	0 -25mg/ml	SAMPLES BELOW 0 SAMPLES ABOVE 7
AMMONIA	11.2 - 15.9mg/ml	0 - 10mg/ml	SAMPLES BELOW 0 SAMPLES ABOVE 3
CONDUCTIVITY	85.3mSm ⁻¹	0 - 85mSm ⁻¹	SAMPLES BELOW 0 SAMPLES ABOVE 1
CHEMICALS	0	R 1 070 581	0

TABLE 7 : Analysis of data for Darvill WWW using key indicators for the financial period 1995-1996

KEY INDICATORS	NUMERATOR	DENOMINATOR	RESULTS
EFFECTIVENESS			
QUALITY OF WATER E coli	134	161	83%
PHOSPHOROUS	120	120	100
C.O.D	120	120	100%
CHLORINE	175	367	47%
S.S	95	120	95%
AMMONIA	110	120	92%
CONDUCTIVITY	51	52	98%
RECIRCULATION OF NUTRIENTS	0	27 274 000kl	0%
THREAT			
WATER TREATMENT	18 075 195 kl	18 487 743kl	97.70%
FINANCIAL	18 487 743kl	R 9 660 000	1.67kl/R/yr
LABOUR	18 487 743kl	106 706 hrs/ yr	173.26kl/hr/yr
ENERGY	18 487 743kl	14 683 420 kWh/yr	1.25kl/kWh/yr
CHEMICALS	18 487 743kl	R 1 050 560	17.58kl/R
MARGIN			
QUALITY OF WATER E coli	6 - 34 000Ecoli/100ml 4 - 480 000Ecoli/100ml	5Ecoli/100ml	SAMPLES BELOW 0 SAMPLES ABOVE 243
PHOSPHOROUS	1 040 - 2 120mg/l 1 270 - 3 720mg/l	0 - 1000mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 0
C.O.D	100%COMPLIANCE	0 - 75mg/l	SAMPLES BELOW NO RESULTS SAMPLES ABOVE NO RESULTS
CHLORINE	0.15 - 1.6mg/l 0.15 - 1.0mg/l	0 - 0.1mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 192
S.S	26.4mg/l 26.6 - 174mg/l	0 - 25mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 6
AMMONIA	10.3 - 11.4mg/l	0 - 10mg/l	SAMPLES BELOW 0 SAMPLES ABOVE 4
CONDUCTIVITY	89.7 mSm ⁻¹	0 - 85mSm ⁻¹	SAMPLES BELOW 0 SAMPLES ABOVE 1
CHEMICALS	0	R 1051 560	0

2.3.1 EFFECTIVENESS

Data corresponding to the period of study has been analysed to identify indicator trends in Table 5, 6 and 7. Compliance results are given for treated water discharged from Darvill WWW into the Msunduzi river. This indicates the effectiveness of water treatment processes at the Works and whether treated wastewater complies with national water quality standards as set out by DWAF. National indicators of water quality include *E. coli*, SRP, Chlorine, TSS, Conductivity, COD and Ammonia. These variables were analysed in order to determine the effectiveness of water treatment processes at Darvill WWW.

2.3.1.1 *E. coli* (Escherichia coli)

E. coli serves as the indicator organism of the microbiological quality of water. Tests for detection and enumeration of indicator organisms, rather than of pathogens are used. Although there are many pathogens including bacteria, viruses, and parasites (helminths), *E. coli* occur in human sewage and are easier to measure. The coliform group is the principal indicator of suitability of water for domestic, dietetic or other uses. The differentiation of coliform group bacteria yields valuable information about the possible source of pollution in water, and especially its remoteness, because the non-faecal members of the coliform group may be expected to survive longer than the faecal members in the unfavourable environment provided by the water (Greenberg, *et al*, 1992).

Experience has established the significance of coliform group density as a criterion of the degree of pollution and thus of sanitary quality. The significance of the tests and the interpretation of results are well authenticated and have been used as a basis for standards of bacteriological quality of water supplies. As a result of the *E. coli* concentrations, inferences can be made about the overall microbiological quality (Greenberg, *et al*, 1992). Due to the health-problems that are associated with poor microbiological quality it is necessary to achieve the required level of compliance. Certain waterborne diseases such as dysentery and diarrhoea are linked to high levels of non-compliance. Apart from problems that affect the well being of humans, the ecology and the ecosystem can also be affected.

Micro-organisms including *E. coli* tend to be adsorbed onto the solid phase (sludge factors) in sewage treatment which also acts as a host and encourages the growth of micro-organisms. Problems associated with low compliance of TSS may increase non-compliance with *E. coli* standards. Hence one of the initial steps in wastewater treatment is the sedimentation of solids and secondary (even tertiary) sedimentation steps are crucial to the success of sewage treatment processes in reducing the number of pathogens or indicator organisms (*E. coli*) in treated effluent. This process, together with chlorination of treated water is responsible for the removal of pathogens.

Source

Domestic sewage is the main source of *E. coli* in wastewater.

Trend and reasons for trends

Figure 7 shows decreasing compliance from 92% during 1993-1994 to 85% during 1994-1995 and 83% during 1995-1996. This implies a reduction in the quality of treated water. This deterioration has been linked to industrial effluent of poor quality. SOG tend to form emulsions with liquid thereby hindering the sedimentation process and resulting in poor clarification of wastewater. This leads to an increase in treated (final) effluent TSS concentrations. Solids in wastewater carry pathogens including *E. coli* with them and this leads to a deterioration in the microbiological quality and higher concentrations of *E. coli* in treated water.

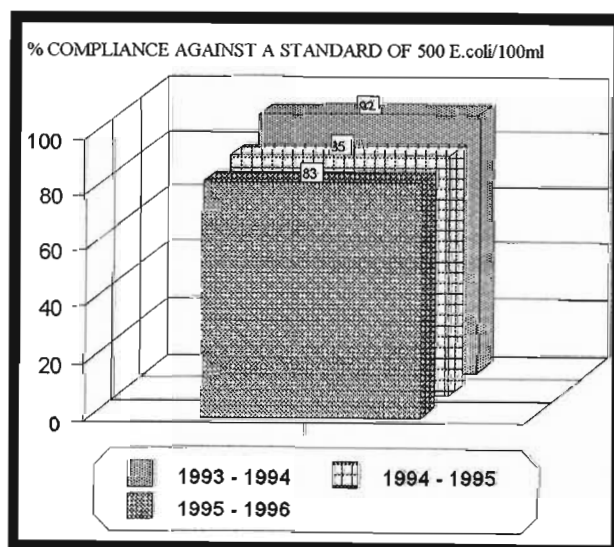


Figure 7 Annual compliance of *E. coli* from 1993-1996

Impacts of the trend

A recent study by Dickens and Graham (1996) indicates that the water quality of the river below Darvill WWT failed to meet the required standard. However this study states that there is little evidence to indicate that the high *E. coli* concentrations of treated water have made a major contribution to the deterioration of the biota of the Msunduzi river, but the nature and time span of the study does not allow for sufficient inferences to be made. High *E. coli* concentrations have been associated with many diseases that may affect downstream users. It is necessary to carry out further studies in order to assess whether users of the Msunduzi downstream from the Works are being affected by the reduced compliance of *E. coli* levels.

2.3.1.2 Soluble reactive phosphate (SRP)

Phosphorous is essential to the growth of organisms and can be the nutrient that limits the primary productivity of a body in water. In instances where phosphate is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage or certain industrial waste into that water may stimulate the growth of photosynthetic aquatic micro- and macro-organisms in nuisance quantities (Greenberg, *et al*, 1992).

Darvill WWT uses of the biological process of phosphate removal but when conditions are not favourable it is necessary to dose chemicals to produce the standard requirements. Phosphorous is a nutrient for plant life. An increase in the phosphorous concentration of aquatic-systems results in increased algal concentrations which adversely affect the natural food chain and both aquatic plant and animal life. The algal eating population increases. Ideally phosphorous should be recycled and used for agricultural processes but this is not always possible due to the large amount of capital that this requires.

Phosphorous removal can be carried out by both chemical and biological processes. The addition of chemical salts (typically metal salts of aluminium sulphate and iron chloride) results in coagulation and precipitation of phosphates. Aluminium and iron form complexes with phosphate that results in an insoluble precipitate that is removed as sludge.

An adverse effect of the addition of these salts is that the sulphate and chloride ions tend to increase the conductivity of the treated water. Phosphate forms storage products with a group of bacteria in activated sludge. This is a highly selective process that requires a larger capital injection for specialised pumps and equipment and a larger energy component. Among the advantages claimed for physio-chemical plants are savings in space and better control of processes based on physio-chemical principles than is possible with biological processes. The question of costs however varies depending on the situation (Murray, 1987).

Source

The major contributors of phosphorous to sewage are human faeces, urine, soaps, household detergents and water softeners. Industrial sewage usually contributes very little to the overall soluble phosphate concentrations but there are certain exceptions like industrial processes which use phosphoric acid. These include the photographic/ film producing outlets and vegetable oil refining and soap producing industries. The waste from vegetable oil refining industries can contribute phosphates by virtue of the seed material (raw material as an oil source is often rich in naturally stored phosphate (phosphogen) compounds).

Trend and reasons for trend

Figure 8 indicates a fluctuation in compliance data from 1993-1996. SRP compliance results decreased from 92% during 1993-1994 to 87% during 1994-1995 and to 100% in 1995-1996. This correlates with the compliance data for TSS. However problems have been noticed with industrial effluent on specific occasions. These data give the overall annual results for compliance hence data at specific times during each year may produce different results due to disturbances at the Works (i.e. incidences when effluent of poor quality enters the Works). Disturbances (e.g. incidences when effluent of poor quality enters the Works). The aim of Darvill WWW is to achieve 100% compliance in order to protect downstream water sources from eutrophication (eg. Inanda Dam-water source for the greater Durban area).

The main reasons for improved SRP compliance are:

- chemical dosing initiated in July 1993 to improve chemical phosphate removal . The operating costs of this are high, depending on the dose and process options used (approximately R 500 000 to R 2.0 million per annum).
- A major initiative (including a capital investment of about R20 million) from 1993 to 1996 to improve biological phosphate removal through the use of nutrient removal technology (modified activated sludge processes)

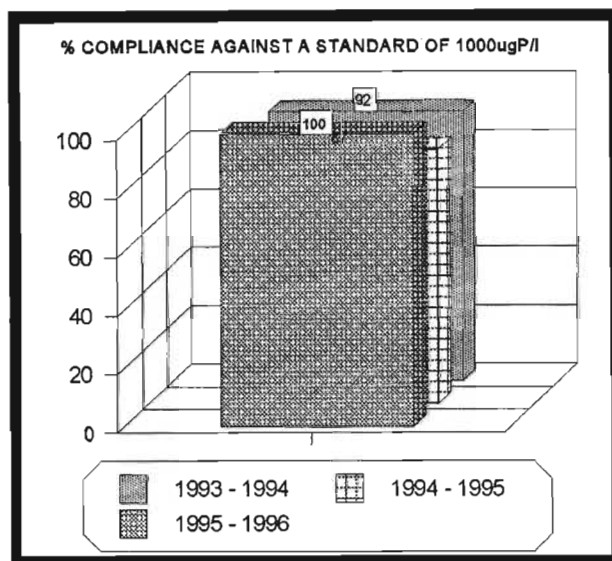


Figure 8 Annual Compliance of SRP from 1993-1996

Impact of the trend

Increased phosphorous concentrations upsets the natural system as a result of altering the food chain. Dickens and Graham (1996) show no indication of adverse effects of the non-complying phosphorous concentrations to the river system downstream from Darvill. This study looks at the comparison between biota of the Msunduzi upstream from the works and that of the river downstream from Darvill. However more intensive analysis of data over a shorter period gives a different perspective.

As a result of impaired aeration, nitrification (breakdown of Ammonia to nitrate) and biological phosphate uptake can be hampered.

The result is that sometimes an increased Ammonia concentration, but more commonly, increased SRP concentration, leaves the activated sludge plant via the secondary effluent (which then becomes final effluent after chlorination for disinfection). The SRP of the final effluent discharge is regulated by the Special Phosphate Standard for reasons of eutrophication control. Ammonia is regulated by the General Standard for discharge to river, for reasons of its toxicity to aquatic organisms.

Although it is difficult to prove a positive link, oil and grease discharges appear to be associated with sewage quality problems, such as very high (or sometimes very low) pH or high concentrations of soluble phosphate (possibly of phosphoric acid origin, which is used in some of the refining processes by the oil industries, figure 9. Figure 9 highlights incidences when increased non-compliance of SRP was linked to SOG related disturbances. Along with impaired aeration, these can inhibit the biological process (e.g. complete impairment of nitrification) or overload it (e.g. sudden increases in phosphate concentrations in the influent sewage can reflect as the same in the secondary and final effluent since the phosphate removal capacity of the plant is limited, being designed for normal domestic sewage, with a controlled fraction of trade effluent).

Phosphorus removal capacity can only be increased by increased dosing of chemicals (e.g. alum or ferric chloride and lime), but the effect is not instantaneous and the dosage cannot be increased suddenly by large margins since there is a limit to the tolerance of the biological system of simultaneous chemical addition.²

Separate (or tertiary) chemical dosing systems for phosphate removal in which the chemicals are added separately to the treated effluent rather than directly to the activated sludge plant are) relatively expensive, requiring additional capital and operating expenditure which has not been possible at Darvill. The tertiary systems also do not take advantage of certain beneficial effects which the chemicals (at low doses) have on the biological system.

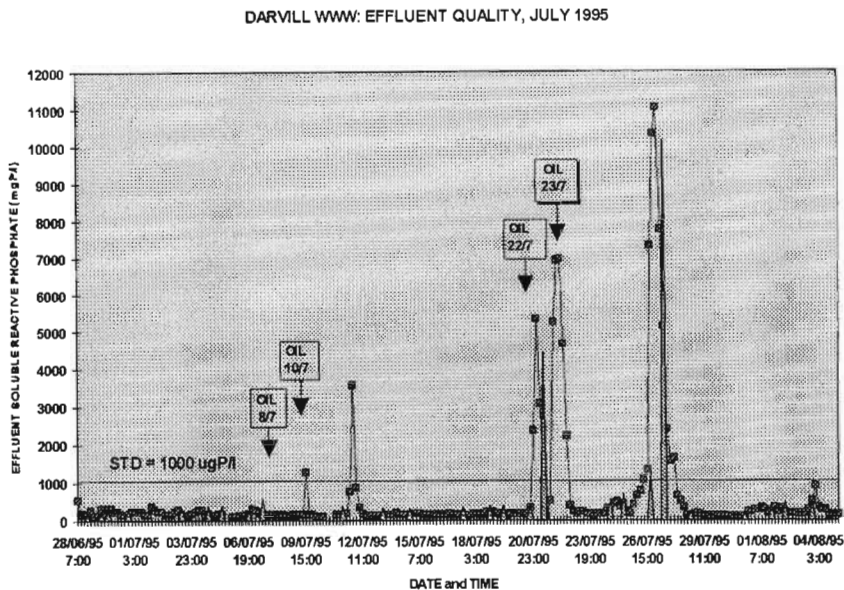


Figure 9 Apparent link between oil discharges to Darvill WW and final effluent SRP Source: de Haas, 1996

2.3.1.3 CHEMICAL OXYGEN DEMAND (COD)

The process by which organic waste is broken down into component parts requires a large consumption of oxygen. The amount of oxygen consumed depends on the magnitude of the waste load. Dissolved oxygen is commonly used to keep track of ambient conditions. The COD is a measure of the oxygen demand placed on a stream by any particular volume of effluent and is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. For samples from a specific source, COD can be related empirically to biological oxygen demand (BOD), organic carbon or organic matter. This test is useful for monitoring and control after correlation has been established (Greenberg, *et al*, 1992).

All higher life forms in a watercourse are aerobic; they require oxygen for survival. As a stream's oxygen concentrations fall, fish mortality increases with the less tolerant fish being the first to succumb. Oxygen concentrations can become low enough that even aerobic bacteria die.

When this happens, the stream becomes anaerobic and the ecology changes drastically. The COD is a measure of oxygen that is required for maintaining natural biota while BOD (biological oxygen demand) is a major fraction of COD. Almost all freshwater systems exert an oxygen demand and non-compliance with COD standards results in ecological disturbances. The COD is measured as material that can be oxidised to carbon dioxide by dichromate. High COD concentrations indicate a drop in the oxygen concentrations available in the water.

Impaired aeration can be caused by the presence of an oily film on the surface of the activated sludge plant (which is equipped with surface aerators). The transfer of oxygen into wastewater or activated sludge is naturally lower than into clean water, and it is reduced even further by the presence of large amounts of oil or oily emulsion in the wastewater (de Haas, 1996).

Source

The removal of suspended organic material reduces the oxygen demand of treated water. Organic material such as oil increases COD and reduces compliance. At Darvill WWW solids are removed from sewage by sedimentation to produce sludge. Problems with sedimentation of solids result in an increase in the concentration of TSS and reduced settleability. An increase in TSS concentration results in an increased growth of large colonies of bacteria being present in treated water. These bacteria tend to rob treated water of oxygen. Bacteria in treated water place a demand on the oxygen in the water therefore *E. coli* and TSS concentrations also affect COD concentrations.

Trend and reasons for the trend

Figure 10 indicates fluctuating compliance results from 1993-1996. Compliance fell from 100% during 1993-1994 to 96 % during 1994-1995, then increased to 100% during 1995-1996. The trend indicates a reduction in compliance from 1993-1995. This is associated with the non-compliance of *E. coli* and TSS. As mentioned above industrial effluent problems have been associated with this non-compliance. However during 1995-1996 compliance improved to 100%. This does not correlate with reduced compliance of *E. coli*. The reason for the lack of correlation between COD, TSS and *E. coli* is the

For example, the TSS standard is 25mg/l while the COD/TSS relationship is 1.1. Therefore while TSS non-compliance will occur for total suspended solids >25mg/l, COD non-compliance will result from TSS > 45mg/l. This could be explained by carrying out further investigations into the correlation between aerobic and anaerobic micro-organisms, *E. coli* and COD as determinants for compliance monitoring.

The compliance of COD is not very sensitive because Darvill WWW has the advantage of receiving relatively dilute sewage. This translates into a small non-biodegradable COD fraction which leaves the Works in the final effluent. The COD standard is 75mg/l and a COD result of 20-40mg/l is usually obtained, meaning that industrial effluent can push the COD to almost double before any threat of non-compliance emerges. Hence it is relatively easier for the Works to achieve compliance with the general standard.

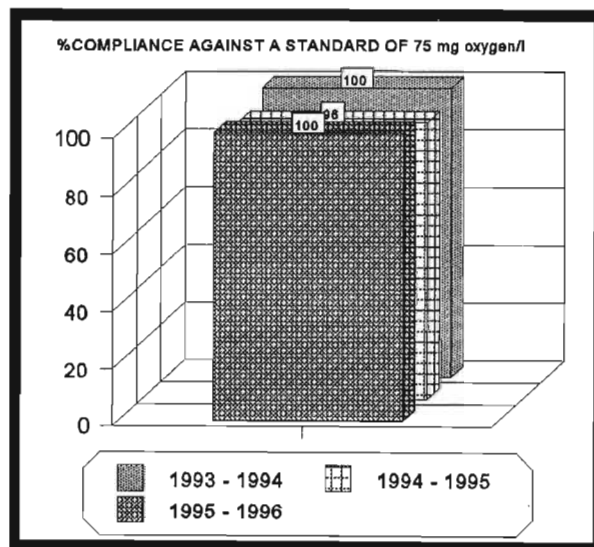


Figure 10 Annual Compliance of COD from 1993-1996

Impacts of the trend

Dickens and Graham (1996) shows no indication of the biota being severely affected. Samples were taken both upstream and downstream from the Darvill WWW and the data appears to correlate, indicating that the COD of treated water does not impact on the quality of the river down stream. The natural ecosystem is better able to react to a steady increase or steady decrease of variables.

Evidence indicates that problems may arise when there are fluctuating conditions. The fluctuating trend that is noted for COD can have negative implications. Both plant and animal organisms thrive in an environment which is not constantly changing.

2.3.1.4 CHLORINE

Free Chlorine is added to water in an attempt to disinfect treated water. Disinfection is the final process in the treatment of wastewater and refers to promoting bacteriological sterility by destroying bacteria, viruses and all other types of microbiological life. The options available for disinfection include the use of Chlorine, ozone and bromine chloride (Murray, 1987).

Before treated water is discharged to the river, Chlorine must be removed, usually through dissipation. An increase in the Chlorine concentrations of treated water will result in the natural biota of the river being negatively affected. Chlorine is toxic to almost all living organisms but some organisms are more sensitive than others. Chlorine not only kills pathogenic micro-organisms but it also affects the natural biota of the river.

Source

All of the free Chlorine that is found in sewage is a result of the disinfection process, as Chlorine is dosed to get rid of bacteria. High COD, TSS and *E. coli* concentrations result in more disinfection being necessary. Less Chlorine is available when there is more organic material present. Organic material and increased TSS pose a Chlorine demand purely on chemical grounds. Disinfection is most effective when there is free Chlorine present.

Trend and reasons for the trend

Figure 11 indicates a markedly increasing trend in compliance data for Chlorine, from 1.3% during 1993-1994 to 21% during 1994-1995 and 47% during 1995-1996. The rapid improvement in compliance is attributed to the new maturation river that was commissioned during 1994.

During this period the effluent was heavily chlorinated to cope with alteration to the Works. Chlorine compliance during this period was very poor. The river allows bacteria to be killed by the sun and for the dissipation of Chlorine thereby reducing the Chlorine concentrations of the treated water. Heat from the sun converts free Chlorine radicals to Chlorine gas which is then dissipated.

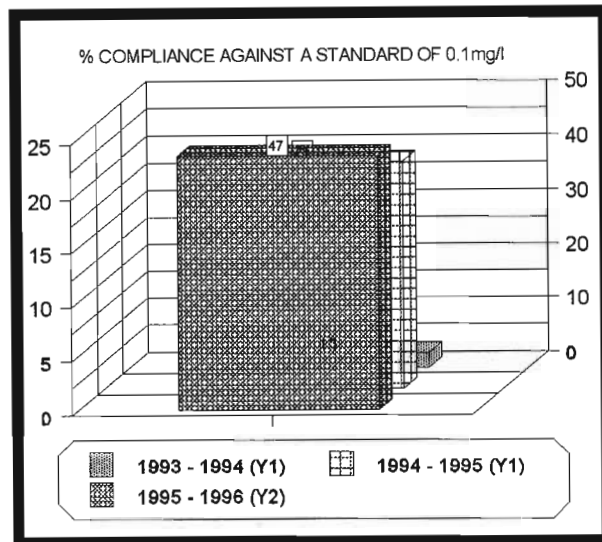


Figure 11 Annual Compliance of Chlorine from 1993-1996

Impact of the trend

The trend observed in figure 11 implies that the level of toxicity due to disinfection, should have decreased, downstream from the Works. As a result there should be an improvement to the natural biota in the system. The Dickens and Graham (1996) study lacks sufficient information to support this deduction. Another reason may be that the river biota are so sensitive to Chlorine that a standard as low as 0.1mg/l may still be too high. As the study was carried out over a short period of time there is insufficient data to analyse the condition of the Msunduzi river during this period.

2.3.1.5 TOTAL SUSPENDED SOLIDS (TSS)

Total suspended solids indirectly affect the compliance of SRP, *E. coli*, COD, Chlorine, and all pathogens and indicator organisms. Increased TSS have a negative impact on these various indicators. As a result problems that are associated with TSS affect the overall conditions and various indicators of the river downstream from the Works.

The effects of TSS are a reduction in numbers of species and sizes of populations and the elimination of filter feeders. The deposition of silt ultimately reduces the diversity of river bed habitat as it destroys the roughness of the bed. In many cases TSS are rich in organic materials and as a result, their deposition brings about an increase in bacterial action and reduction in dissolved oxygen in the surface sediments (Thomas, 1974).

Source

The solid component of sewage is removed through sedimentation in the primary settling tanks, (appendix B explains the operation of Darvill WWW). After the sewage is screened it is passed through a series of flow tanks resulting in denser particles of sand and grit migrating to the bottom of the tanks where they are pumped out. Thereafter raw sewage enters a distribution box and splits into primary settling tanks where sludge particles settle to the bottom, this primary (raw) sludge is scraped from the bottom of the tanks and channelled to the pre-thickener. The overflow from the primary settling tanks (known as settled sewage) gravitates into the balancing tank. Illegal industrial discharges into the sewer system have a detrimental effect on the biological treatment process. Industrial discharges such as oily and sticky waste products, soaps and by-products of margarine manufacture cause considerable problems. When this occurs sludge particles do not settle, clogging the surface of the tanks and interfering with later treatment processes.

Trend and reasons for the trend

Figure 12 shows an increase in TSS compliance from 88% during 1993-1994 to 92% during 1994-1995 and 96% during 1995-1996. This does not correlate with problems that have been experienced with *E. coli* and SRP but this trend is noticeable with Chlorine. Efficiency of the treatment processes with respect to COD and Chlorine appear to have improved, although compliance with *E. coli* and Ammonia standards have decreased. Improvements are largely attributed to the improvements in clarifiers, oil and scum removal as well as the efforts of Works operating and maintenance staff.

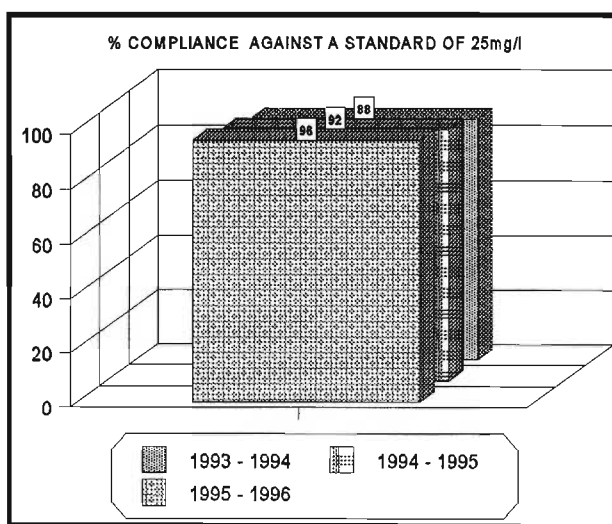


Figure 12 Annual Compliance of TSS from 1993 -1996

Impact of the trend

According to Dickens and Graham (1996) there are no noticeable impacts on the ecosystems as a result of the increased compliance but it is expected that the quality of natural biota should have improved. However the scope of this study does not include sufficient data to analyse the impacts on the river biota during 1993-1996. Although compliance has improved it has been suggested that the quality of effluent has deteriorated, particularly industrial effluent. Further study of the quality of industrial effluent and its impact on the operation of the Works is needed.

Figure 13 illustrates the worsening sludge settleability (determined as an increase in Dilute Sludge Volume Index, or DSVI) of the Darvill WWW activated sludge plant during 1996. Note the increase from May 96 to September 96, due to *Nocardia* scum problems exacerbated by the oily influent received. One of the main control variables which could have affected sludge settleability during this time, alum dose, remained essentially constant through the period examined. From research elsewhere in the world, there is evidence which supports the connection between a high concentration of emulsified oil and grease in the sewage and growth of *Nocardia*-type organisms. These organisms are filamentous and have been identified as being common in the Darvill WWW activated sludge in recent months (August-September, 1996), whereas they previously were not commonly found.

The link between the growth of filamentous organisms such as *Nocardia* and weakened sludge settling is a well known phenomenon in wastewater treatment. The consequences of a deteriorating DSVI (poorer sludge settling or settleability) are serious. The worse the sludge settleability, the more secondary clarifier capacity is needed to treat the same flow.

The secondary clarifier capacity at the Works was increased by 66% during the 1992-3 upgrade, although this was due to the original three clarifiers being of too small to deal with particularly the high wet weather flows to this Works (i.e. not linked to the oil problem). However, normally (i.e. without trade effluent problems), the Works has a good settling sludge with a DSVI of about 60 to 85 ml/g, with some seasonal variation. In recent months, this has deteriorated to some 115 ml/g, and the most likely explanation for this is the increased presence of nuisance *Nocardia*-type organisms (de Haas, 1996).

From clarifier theory, the consequence of a weakening (increase) in DSVI is that the capacity of the clarifiers is reduced by approximately 40%. In other words, whereas at a DSVI of approx. 75 ml/g, the clarifiers would be able to treat up to about 120 ML/d (twice ave. dry weather flow), at approx. 115 ml/g, the same clarifiers under the same operating conditions will only be able to treat up to about 72 ML/d (dry weather flow of 60 ML/d plus about 20%).

Hence, it may be said that the settling problems, which appear to be linked to the oil problems, have resulted in clarifier capacity being used up. This has a capital worth (in 1993 Rands) of about R1.05 million (R1.4-million during 1996). With interest and redemption (at a favourable rate) over 20 years, the “lost” clarifier has a present value of about R200 000 per annum.

Alternatively, one could argue that the additional clarifier capacity needed to make up for that “lost” (due to weaker settleability) should be accompanied by additional reactor (i.e. treatment) capacity too. In this case (see above) the capital cost would be at least R21 million (or R2 million per year over 20 years, with interest and redemption), and it may be as high as R40million (or R5 -million annually over 20 years with interest and redemption), depending on the assumptions made (de Haas, 1996).

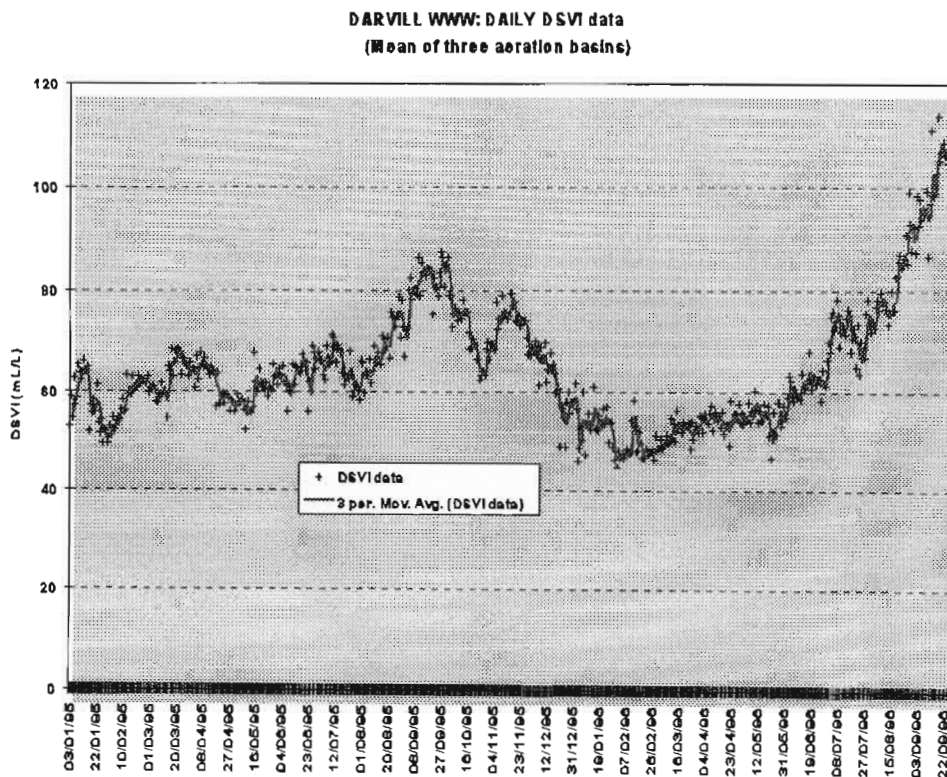


Figure 13 DSVI data for Darvill WWW for 1995-1996

Source: de Haas, 1996

2.3.1.6 AMMONIA

Ammonia is highly toxic to almost all aquatic life including fish. Recent studies by ecologists indicate that the standard requirement of 10 mg/l may still be too high. A lower standard has been recommended. However achieving compliance with such a low standard appears to be impossible using either the biological treatment process or an economically feasible chemical process. Since Ammonia concentrations of sewage tend to be relatively high, adequate monitoring and control is necessary.

Source

The main source of Ammonia appears to be human sewage. Compared to industrial effluent, the quantity and quality of domestic sewage has not changed significantly. Apart from faeces and urine, domestic sewage contains wastewater from dish washing, laundering and ablution which also act as sources of Ammonia to wastewater.

Trend and reasons for the trend

Figure 14 indicates decreasing compliance from 100% during 1993-1994 to 94% during 1994-1995 and 92% during 1995-1996. Since the quality and quantity of the source of ammonia has not changed significantly the changes in the trend can be attributed to interferences in the treatment processes. A lack of compliance is associated with aeration and nitrification problems. Ammonia concentrations of secondary effluent are monitored every four hours and this is the "pulse" of an activated sludge plant. Ammonia concentrations are measured at relatively short intervals for controlling aeration. It would be easier to find trends if a greater range in compliance data existed. Figure 15 illustrates the apparent link between decreasing compliance and sewage containing large concentrations of oily effluent. Decreasing compliance with the Ammonia standard is linked to sewage containing large concentrations of SOG.

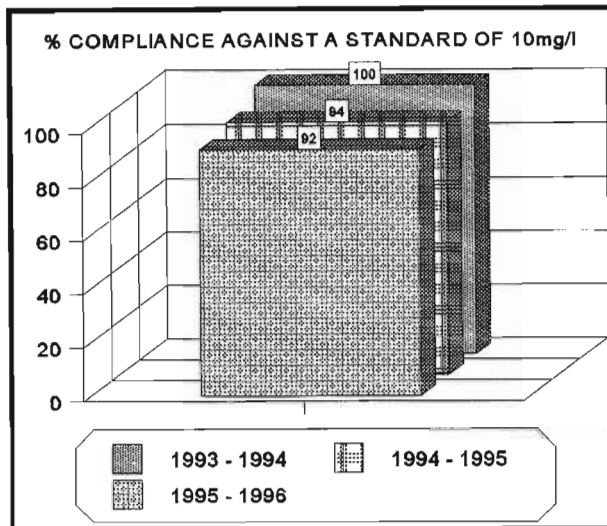


Figure 14 Annual Compliance of Ammonia from 1993-1996

Impact of the trend

Dickens and Graham (1996) indicate that there is insufficient proof to indicate that the river biota has been affected as samples taken upstream from the works correlate with samples taken downstream. It is expected that the long-term decrease in compliance may impact negatively on the natural ecosystem of the river.

DARVILL WWW : EFFLUENT QUALITY, JULY 1995

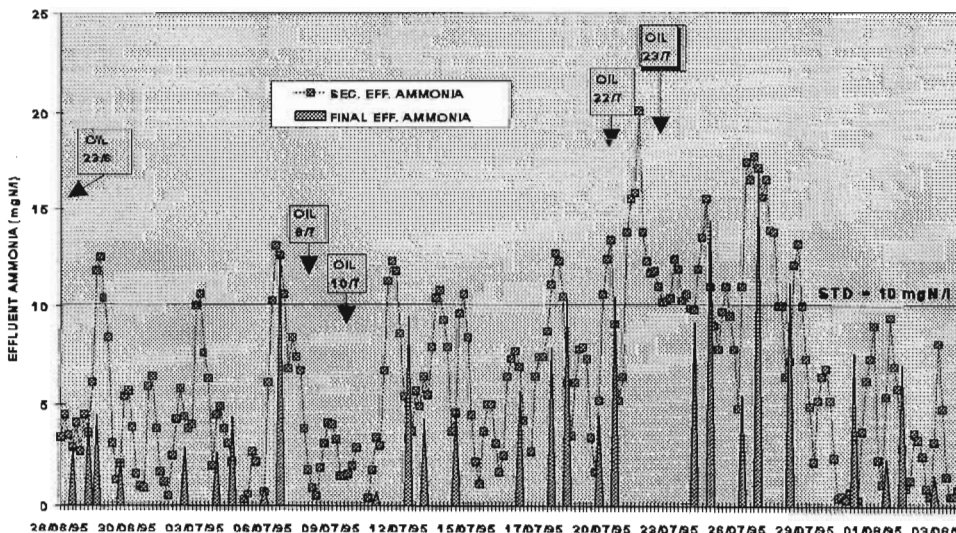


Figure 15 Increasing non-compliance with the Ammonia standard due to oil discharges. (Source de Haas, 1996)

2.3.1.7 CONDUCTIVITY

Conductivity is a measure of the total dissolved salt concentration in water. All aquatic organisms are affected by conductivity of water. Conductivity must remain constant as it affects the hydration of all aquatic biota.

Source

The biological treatment process produces little change to the conductivity of treated water since there is no significant removal of dissolved salt. Chemicals added during treatment processes increase the salt concentration of the water hence marginally increasing the conductivity. Some industrial effluents also affect the conductivity of treated water, the effluent from the textile industry in particular has a high conductivity.

Trend and reasons for the trend

Figure 16 indicates a constant trend with the conductivity standard. During the period between 1993-1996 conductivity compliance remained constant at 98%. The Works does not experience conductivity problems since the source of water from Midmar Dam is of relatively low conductivity and requires polymers that have a negligible impact on conductivity for clean water treatment. The Works is also able to comply, with the standard as the high conductivity concentrations of industrial effluent is neutralised by the low concentrations of domestic sewage.

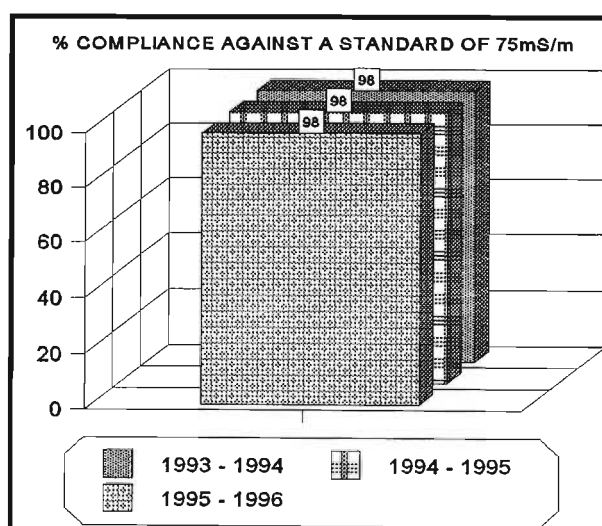


Figure 16 Annual Compliance of Conductivity from 1993-1996

Impact of the trend

Compliance data for conductivity has remained constant, so it is unlikely that the river system has been affected. Darvill WWWW manages to maintain compliance with the standard.

2.3.1.8 RECIRCULATION OF NUTRIENTS

This is an indicator of the percentage of nutrients (phosphorous) that is recirculated. Recirculation of phosphorous is the amount of sludge recirculated in agriculture divided by all the sludge produced. It is difficult to measure the recirculation of phosphorous at Darvill WWWW since the plants relies heavily on biological methods of treatment instead of chemical processes. The biological process allows phosphorous to precipitate out as sludge. The measure of sludge produced is therefore an approximate indicator of the amount of organic material, heavy metals and phosphorous being precipitated. Since none of the sludge is recycled for agricultural use, it is assumed that none of the phosphorous is recycled. It is also assumed that the biological process attempts to remove almost all the phosphorous in the sludge.

Ideally a sewage treatment plant should allow for the recycling of nutrients. This would indicate an environmentally sound operating plant. This however is not possible because in order to effectively recycle sludge it has to be adequately treated. Sludge contains pathogens and heavy metals as well as nutrients. In order to monitor pathogens and heavy metals, a large capital injection is necessary for composting and thermal drying equipment. Sludge though contains a lower concentration of nitrogen and phosphorous than commercial fertiliser. The need for changes to the current sludge disposal method is recognised by UW, DWAF, and the Pietermaritzburg City Planning Department. However the current method is the cheapest. The financial feasibility of alternative processes needs to be investigated since composting has been estimated to be the best alternative. The current scenario favours economic benefits over environmental benefits. Increasing environmental awareness and a study of alternatives requires immediate attention.

The quantity of sludge can be minimized through processes of waste minimization and controlled on site treatment of effluent. Treated effluent can also be used as secondary grade wash water in the factory. This will limit the amount of sludge and phosphorous being wasted, but the future of sludge disposal at Darvill WWW is still uncertain.

As the City grows and the total load to Darvill WWW increases, other sludge disposal options will need to be considered. Various options have been put forward for more advanced sludge treatment and disposal, including:

- Co-disposal with domestic refuse at the local landfill situated on New England Road;
- High lime process after transporting by rail outside the City;
- Composting on site at Darvill and transporting the product to the City perimeter or beyond;
- Thermal drying and transporting of the dried product to the City perimeter or beyond;
- Incineration and transporting the ash to the City perimeter or beyond .

Of these options the most likely alternative appears to be composting. The capital estimate for composting is the most realistic and has a proven record of success compared to the other alternatives. The high lime process has never been used in the country and thermal drying is a relatively new option. As a result exact costs and the success of these operations cannot be accurately assessed. Incineration is extremely energy intensive and therefore expensive (de Haas, 1997).

2.3.1.9 SUMMARY AND CONCLUSIONS

The effectiveness of wastewater treatment processes at Darvill WWW was analysed according to trends in *E. coli*, Chlorine, Soluble Reactive Phosphate (SRP), Total Suspended Solids (TSS), Conductivity, Chemical Oxygen Demand (COD) and Ammonia. Varying trends were observed with respect to these variables.

E. coli compliance decreased from 92% to 83% during 1993-1996. Compliance of SRP decreased from 92% to 87% during 1993-1995 and increased to 100% during 1995-1996, while COD fell from 100% to 96% then increased to 100% during this period. Chlorine and TSS compliance rose markedly from 1.3% to 21% then 47% and 88% to 92% then 96% respectively during 1993-1996. Ammonia compliance results decreased from 100% during 1993-1994 to 94% during 1994-1995 and 92% during 1995-1996. A measure of conductivity indicates a constant trend of 98% compliance each year.

The reasons for varying compliance data have been attributed to disturbances at the Works, due to industrial effluent of poor quality. However, management seems aware of these disturbances and attempts are being made to determine their source. Large amounts of capital have been injected into the renovation and maintenance of the Works. Treatment processes appear to be effective with respect to certain variables. *E. coli* and Ammonia seem to be decreasing in compliance while Chlorine and TSS compliance has increased. The other variables produce fluctuating trends.

Effectiveness of nutrient recycling has remained constant at zero through the duration of the study as Darvill WWT does not engage in any form of nutrient recycling due to the costs involved. Alternate methods of sludge disposal are being considered and this may change.

Due to the large capital injection it appears that the effectiveness of the overall treatment process has improved. Problems of non-compliance are most likely due to the poor quality of industrial effluent that is coming into the Works. Analysis of thrift in the next variable will determine the costs of improved wastewater treatment.

2.3.2 THRIFT

Thrift determines the costs involved in treating wastewater and is analysed using financial, labour, energy and chemical cost variables. Financial thrift is a ratio of kilolitres of wastewater treated per rand of capital (initial and additional capital). Energy thrift is a ratio of kilolitres of wastewater treated per kilowatt hour of energy consumed. Chemical thrift is a ratio of kilolitres of wastewater treated per rand of chemicals consumed. Labour thrift is a ratio of kilolitres of wastewater treated per man hour of labour.

2.3.2.1 FINANCIAL THRIFT

This gives capital costs in comparison to the volume of incoming dry weather inflow³ (kilolitres of incoming dry weather inflow divided by annual cost of capital). The financial thrift looks at the amount of capital that is required for the operation of the plant (initial capital plus additional capital which is extensions and new equipment for renovations).

Trend and reasons for the trend

Figure 17 indicates a decrease in financial thrift from 2 kl/R during 1993-1994 to 1.75 kl/R during 1994-1995 and 1.67 kl/R during 1995-1996. The decrease is attributed to an increase in the volume, and a decrease in the quality, of effluent entering the Works. The plant appears to have become less thrifty with respect to capital during the past three years. This means that less kilolitres of effluent are being treated per rand or more capital per volume is required to treat wastewater. Increasing capital is due to an increase in additional capital due to recent extensions and renovations to the Works. Increasing costs for maintenance of equipment has also affected financial thrift. The costs of trying to achieve compliance with national standards has increased since 1993.

³dry weather inflow - this was calculated for the winter months of June, July, August with the assumption that these are the driest months of the year. It was assumed that there was almost no rain during these months and that all influent was free of any storm water. It is therefore assumed that the calculated sewage volumes do not include treatment for stormwater hence only domestic sewage and industrial effluent is included.

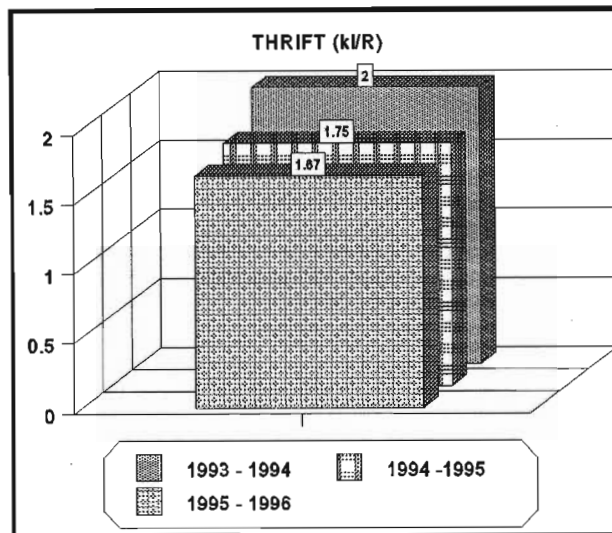


Figure 17 Annual Financial thrift from 1993-1996

Impact of the trend

To deal with changing quality and quantity of effluent more capital is required for additional equipment such as skimmers and sprayers. These modifications are required in order to improve the efficiency of the plant and to ensure that the plant is meeting standards. Additional capital is needed for these extensions and for increased clean up costs. Since the City Council of Pietermaritzburg does not enforce the “polluter pays” principle, the organisations who are responsible for increased pollution are not responsible for clean up costs. They are being subsidised by the Council (City ratepayers) and UW. To achieve compliance with national standards and to maintain and improve the efficiency of the plant more capital is required.

2.3.2.2 LABOUR THRIFT

This is defined as kilolitres of incoming dry weather inflow divided by the number of hours of labour per year needed to support the system. The labour thrift looks at the amount of labour in hours that is required to efficiently operate the plant.

This is not a clear indication as casual labour which has increased, is unaccounted for. It has been necessary to employ up to 20 additional workers on certain occasions. The number of permanent casual labourers increased from 0 during 1993-1994 to 6 during 1994 -1995 to 8 during 1995 - 1996. Additional casual labour is required for cleaning out tanks, cleaning the maturation river, and for maintenance. An increase in the costs of labour is evident from increasing manpower costs.

Trend and reasons for the trend

Figure 18 indicates an increase in labour thrift from 155.34 kl/hrs/yr during 1993-1994 to 173.26 kl/hrs/yr during 1995-1996 but this an incorrect reflection as casual labour is not taken into account. It appears as though more kilolitres of effluent are being treated per man hour. This is not correct as the ratio only considers permanent staff of UW. It is evident from records at Darvill that the number of permanent employees dropped from 42 during 1993-1994, to 38 during 1994-1995 and 36 during 1995-1996. Hence the increase in labour thrift. However the number of casual workers during this time increased from zero to eight. Casual labour is now contracted out (1996). Increasing manpower costs have however highlighted the increase in labour costs. It is cheaper for UW to make use of casual labour rather than permanent labour. Casual employees do not demand the benefits that are given to permanent employees. An added advantage is that there is no threat of strikes and other human resource problems. However this shift results in a negative effect on the quality of employment at Darvill. The increasing reliance on casual labour affects workers negatively since they have insecure, casual jobs with no benefits. This may be partly due to the cost pressures arising from the deteriorating quality of effluent.

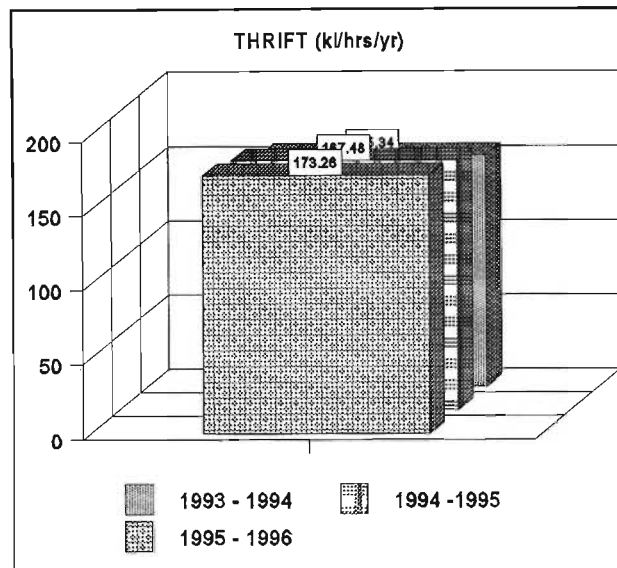


Figure 18 Annual Labour Thrift from 1993-1996

Impact of trend

It is not evident from the analysis but according to the management of Darvill WWW, total labour hours have increased as result of disturbances such as poor quality effluent containing high concentrations of SOG have resulted in specific problems. Extra labour is required to clean out the tanks covered with oil and grease and the capacity of the tanks is reduced, the clarifiers are also affected by the high SOG concentrations and the maturation ponds need to be regularly cleaned out. The clean up costs are difficult to estimate especially where full-time labourers may be drawn off another task and dedicated to cleaning up oily effluent. The approximate costs are R20 000 per month (excluding capital costs due to diminished plant capacity). On some occasions it was necessary to call in outside contractors to remove scum, oil and grease from various tanks and to dump it at the screening trenches at Darvill WWW. The contractors bill to UW which did not include transport for dumping amounted to R6 600 for a two day clean-up and R12 600 for a three day clean-up. This is not a cost effective alternative (de Haas, 1996).

2.3.2.3 ENERGY THRIFT

This is defined as the volume of incoming dry weather inflow divided by the annual energy expenditure (total energy that is required for the operation of the plant). Energy thrift refers to the amount of sewage that is treated per kilowatt hour of energy consumed. The greater the amount of sewage that is treated, the thriftier the plant is in terms of energy consumed. The biological process of phosphate removal demands on a larger energy consumption. This however reduces the chemical costs.

Trend and reasons for the trend

Figure 19 indicates a steady decrease in energy thrift from 2.77 kl/kWh during 1993-1994 to 1.26kl/kWh during 1995-1996. This decrease is partly due to the upgrade of the plant. Extensions to the Works include increased energy costs for a DAF (dissolved air floatation) plant, a flow balance, additional secondary clarifiers, mixers, pumps and skimmers. The increase in energy consumption is also attributed to disturbances that have been experienced. As already mentioned poor quality effluent with high concentrations of SOG have been the cause of major disturbances. Oil skimmers alone require 6.7 kW motors and they run at 24hrs/day. This implies an energy consumption of approximately 170 kWh per day. Similarly, reduced efficiency of surface aerators due to oil in the activated sludge plant could increase electricity consumption by at least 3700 kWh per day. Aeration accounts for a large percentage of the total electricity consumption.

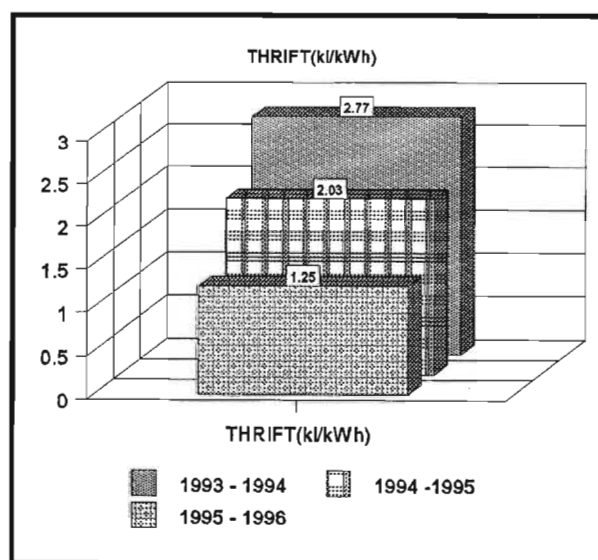


Figure 19 Annual Energy Thrift from 1993-1996

Impact of the trend

The increase in energy demand increases the overall costs of the Works. Darvill WWW relies heavily on the biological method of phosphate removal, which has a high energy demand. Influent of poor quality tends to put a strain on usual energy demands of the works which increases overall costs of operating the Works. The costs of operating the Works are at present being subsidised by the Pietermaritzburg ratepayers. Since the principle of the “polluter pays” is not being adhered to, the current situation needs to be reviewed in order to develop a fair and equitable solution.

2.3.2.4 CHEMICAL THRIFT

This refers to the total kilolitres of incoming dry weather inflow as a ratio of annual cost of chemicals that is required for the operation of the Works. It is calculated in order to assess the amount of chemicals that are required to effectively treat sewage. Chemicals are an important part of sewage treatment, but Darvill WWW limits the use of chemicals as the biological process of phosphate removal is preferred due to a reduction in expected long term operating costs.

Trend and reasons for the trend

Figure 20 indicates a rise in chemical thrift from 9.77 kl/R during 1993-1994 to 17.58kl/R during 1995-1996, confirming an increased reliance on biological phosphate removal. Although an annual increase in thrift is noted, the difference between 1993-1994 and 1994-1995 is much larger than the difference between 1994-1995 and 1995-1996. This is attributed to changes that were brought about at this time to plant and equipment at the Works.

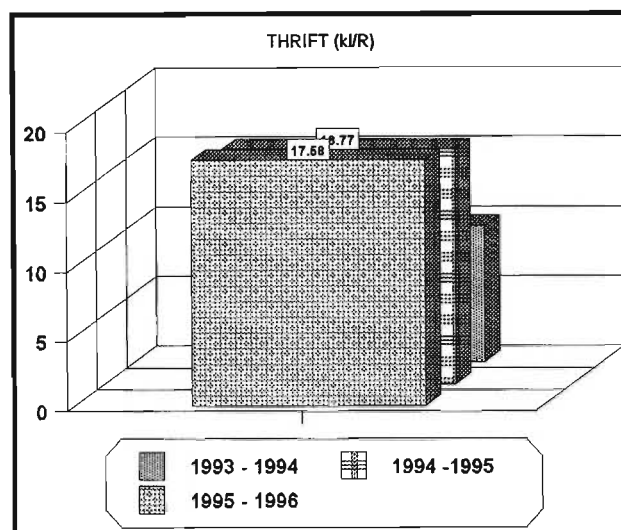


Figure 20 Annual Chemical Thrift from 1993-1996

Impact of the trend

The analysis of chemical and energy thrift indicates that Darvill has chosen the biological process of phosphate removal. This is also reflected in the financial thrift as the plant has been upgraded to deal more with biological processes. These are preferred since chemicals tend to increase the conductivity of the water as a result of the dissolved salts and they reduce operating costs in the long term. The cost/ benefit ratio should decrease in the long term due to the expected benefits of the biological method of phosphate removal.

2.3.2.5 SUMMARY AND CONCLUSIONS

Thrift of the following variables were analysed; finances (capital), labour, energy and chemicals. The costs of treating wastewater were analysed according to the volume of wastewater treated. Financial thrift was calculated in terms of rands, labour in terms of hrs per year, energy in terms of kilowatt hour and chemicals in terms of rands.

Financial thrift decreased from 2.00 kl/R during 1993-1994 to 1.67 kl/R during 1995-1996. Energy thrift also decreased during this period from 2.77 kl/kWh to 1.25kl/kWh. Labour thrift and chemical thrift measures increased from 155.34 kl/hrs/yr and 9.77 kl/R during 1993-1994 to 173.26 kl/hrs/yr and 17.58 kl/R during 1995-1996 respectively.

Reasons for the trends observed include increased capital costs due to recent renovations and extensions. Increasing energy costs were attributed to new equipment and increased reliance on the biological process of phosphate removal. These factors explain the decreasing chemical costs. However increasing labour costs have arisen due to problems being caused by influent of poor quality. The use of casual labour is increasing while permanent staff decreases. It is apparent from the study that the treatment of sewage of deteriorating quality is placing heavier demands on the cost of operating the Works. Industrial effluent in particular is the cause of increasing costs. The responsibility of these increasing costs are not being borne by the people causing the problems.

2.3.3 MARGIN

This shows the marginal difference between the actual range of results and the standard range. It indicates the deviation when 100% compliance with the standard is not possible. Through the measure of deviation from the standard, it is possible to make inferences relating to the severity of non-compliance. Although the Works aims at 100% compliance, this is not always practically possible.

Margin also measures the efficiency and effectiveness of processes at the Works. Reasons for trends observed from 1993-1996 were investigated. As with the analysis of effectiveness, the variables studied were, *E. coli*, Chlorine, SRP, TSS, Conductivity, COD and Ammonia.

2.3.3.1 *E. coli*

Darvill WWWW has serious problems in dealing with *E. coli*. Although the national general standard is 0 *E. coli*/100ml, the Works has been granted a specific standard of 500 *E. coli*/100ml. This was necessary due to the actual range of results being so high. The relaxed standard was only given for the period between 1993-1994 and 1994-1995. However it was not renewed for 1995-1996 and the Works has not reverted to the general standard of 0 *E. coli*/100ml. The effectiveness indicator shows that compliance with the specific standard ranges decreased from 92% to 83%. Darvill currently has two discharge lines, final and old, but discharge from the old line is minimal.

The general standard for *E.coli* is 0 *E. coli*/100ml but a specific standard of 500 *E. coli*/100ml has been obtained. The computer still recognises the general standard hence non-compliance is given for ranges from 6 *E. coli*/100ml.

Trend and reasons for the trend

The range of non-complying results for the final effluent discharge line improved from 6-287 000 *E. coli*/100ml during 1993-1994 to 6-181 000 *E. coli*/100ml during 1994-1995 and decreased to 6-340 000 *E. coli* 100ml during 1995-1996 (Table 8). The reason for actual results starting at 6 *E. coli*/100ml may be linked to discrepancies resulting from standards being used. It may be due to the computer programme adapting to changing standards. The general standard is 0 *E. coli*/100ml and specific standard is 500 *E. coli*/100ml.

The reason for an improvement then deterioration in non-complying samples is not known. Increased compliance and reduced deviation from the standard according to management is attributed to more efficient operation of the Works while a decrease in compliance and increased deviation from the standard is linked to disturbances at the Works due to industrial effluent of poor quality.

TABLE 8: Trend indicating the margin of difference between the range of non-complying samples and the standard *E. coli* result during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL <i>E. coli</i> /100ml	STANDARD <i>E. coli</i> /100ml
1993 - 1994	6 - 287 000	500
1994 - 1995 OLD ⁴	6 - 224 000	500
FINAL	6 - 181 000	500
1995 - 1996 OLD	6 - 480 000	500
FINAL	6 - 340 000	500

Impact of the trend

High *E. coli* concentrations were also documented in the study by Dickens and Graham (1996) Monitoring *E. coli* is important in order to determine the overall quality of water with respect to the effects of micro-organisms. High *E. coli* concentrations are associated with the transmission of many infectious waterborne diseases such as gastroenteritis and cholera and it impacts on important daily activities as indicated by Table 9. Deteriorating quality of industrial effluent has been linked to poor compliance with the *E. coli* standard. This effluent hampers treatment processes and reduces the efficiency of treatment processes. Plant equipment and machinery are also affected.

⁴The Old effluent route since 1995 represents approximately less than 5% of the total flow.

TABLE 9: Activities affected by varying counts of *E. coli* /100ml

<i>E. coli</i> /100ml	DRINKING	BATHING	IRRIGATION
0	negligible risk of microbial infection	suitable for use	suitable for use
0 - 1	slight risk of microbial infection	suitable for use	suitable for use
1 - 10	slow risk of microbial infection is indicated for continuous exposure	suitable for use	suitable for use
10 - 20	Significant risk of infectious disease transmission is indicated with long and short term use	risk of infection	slight risk of contamination
> 20	significant risk of infectious disease transmission is indicated with long and short term use	risk of gastro-intestinal illnesses exist	field crops may be contaminated

Source: *A GUIDE FOR THE HEALTH RELATED ASSESSMENT OF THE QUALITY OF WATER SUPPLIES, DWAF (1996)*

2.3.3.2 SOLUBLE REACTIVE PHOSPHATE (SRP)

The biological method of phosphate removal is more sensitive than the chemical process. Increasing non-compliance with the SRP standard indicates less buffering effect from chemicals since the biological process is now relied upon more heavily at Darvill WWW. Disturbances at the Works tend to affect the biological processes thereby affecting compliance with the phosphate standard.

Trend and reasons for the trend

Table 10 indicates a decrease in the range of non-complying samples from 1 460-2 214 ugP/l during 1993-1994 to 1 140-1730 ugP/l during 1994-1995, then an increase of 1 270-3 720 ugP/l during 1995-1996. This trend is also indicated by the effectiveness indicator. The difference between non-complying samples and the standard decreased from 1993-1994 to 1994-1995 then increased from 1995-1996. Deteriorating compliance has been blamed on the poor quality of industrial effluent particularly effluent containing high concentrations of SOG. No explanation is given for the fluctuation in the trend except that increasing compliance may be due to an increase in efficiency of plant operations but this does not explain why compliance decreased during 1995-1996.

TABLE 10: Trend indicating the margin of difference between the range of non-complying samples and standard SRP results during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL ugP/l	STANDARD ugP/l
1993 - 1994	1 460 - 2 214	0- 1000
1994 - 1995 OLD	1 130- 1 960	0- 1000
FINAL	1 140 - 1 730	0- 1000
1995 - 1996 OLD	1 040 - 2 120	0- 1000
FINAL	1 270 - 3 720	0- 1000

Impact of the trend

A low level of compliance can be detrimental to the ecology in the river downstream from the Works. Increased concentrations of phosphate are toxic to both aquatic plants and animals but the study by Dickens and Graham (1996) indicates that recent SRP concentrations of the river are within compliance. This study however does not highlight specific incidences when SRP concentrations increased as a result of disturbances to the Works. These disturbances include incidences when large concentrations of SOG were noticed at the Works.

2.3.3.3 CHEMICAL OXYGEN DEMAND (COD)

Darvill WWW does not seem to have a problem with COD. It has been stated by management at the Works that COD concentrations on specific occasions were very high. Deteriorating quality of industrial effluent has been blamed for this non-compliance since an increase in non-compliance was noted when industrial effluent containing a large concentration of SOG entered the Works.

Trend and reasons for the trend

During 1993-1994 and 1995-1996 the works achieved 100% compliance however during 1994-1995 a low level of non-compliance was noted. Marginal difference in the range of 93.8-131 mg/l O₂ for the period 1994-1995 is indicated by Table 11 . The fluctuating trend is explained by increased efficiency at the Works but this does not correlate with other variables.

TABLE 11: Trend indicating the margin of difference between range of non-complying samples and standard COD results during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL mg/l O ₂	STANDARD mg/l O ₂
1993 - 1994	100 % COMPLIANCE	0 - 75
1994 - 1995 OLD	97.3	0 - 75
FINAL	93.8 - 131	0 - 75
1995 - 1996 OLD	100 % COMPLIANCE	0 - 75
FINAL	100 % COMPLIANCE	0 - 75

Impact of the trend

Oxygen is vital to any aerobic system and non-complying COD concentrations are associated with negative impacts to these systems. The long term implications of non-compliance with the COD standard may be detrimental to the river ecosystem.

2.3.3.4 CHLORINE

Extensions to the plant appear to have improved the process of Chlorine dissipation. The new maturation river has improved compliance of treated water. The old process involved the use of a small contact tank but the much larger maturation river appears to have improved the efficiency of the works in terms of reducing final effluent residual Chlorine concentrations.

Trend and reasons for the trend

The value of non-complying samples has improved from a maximum of 6mg/l during 1993-1994 to a maximum of 1 mg/l during 1995-1996 (Table 12). Samples taken seem to be getting closer to complying with the standard of 0.1 mg/l. Reasons for increased compliance are due to the renovations and improvements to the Works, specifically the new maturation river which was commissioned recently.

TABLE 12: Trend indicating the margin of difference between the range of non-complying samples and standard Chlorine results during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL mg/l	STANDARD mg/l
1993 - 1994	0.15 -6	0 - 0.1
1994 - 1995 OLD	0.2 -2	0 - 0.1
FINAL	0.15 - 2.2	0 - 0.1
1995 - 1996 OLD	0.15 - 1.6	0 - 0.1
FINAL	0.15- 1.0	0 - 0.1

Impact of the trend

The effects to the ecology as a result of this improvement has not been monitored but it is expected that the ecosystem has benefited as the toxicity of the river has been reduced tremendously. Dickens and Graham's (1996) study was conducted over a short period during 1995 and does not contain sufficient information to substantiate this.

2.3.3.5 TOTAL SUSPENDED SOLIDS (TSS)

Non-compliance with the national standard for TSS is largely due to the scum related problems associated with industrial effluent of poor quality.

Trend and reasons for the trend

Table 13 indicates that the range of non-complying samples has deteriorated over the last three years from a maximum value of 60.2 mg/l during 1993-1994 to 136 mg/l during 1994-1995 and 174mg/l during 1995-1996. Although compliance with the TSS standard increased from 1993-1994, the marginal difference of non-complying samples increased. This implies that those samples that did not comply fell far out of the standard range.

The reason given for this is the poor quality of industrial effluent. During incidences when large concentrations of SOG have been noticed at the Works, TSS concentrations have increased. Incidences of oil and grease pollution to sewage are not always frequent hence the overall compliance results may have increased.

TABLE 13: Trend indicating the margin of difference between the range of non-complying samples and standard TSS results during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL mg/l	STANDARD mg/l
1993 - 1994	28.0 - 60.2	0 - 25
1994 - 1995 OLD	90.8	0 - 25
FINAL	28 - 136	0 - 25
1995 - 1996 OLD	26.6-174	0 - 25
FINAL	26.4	0 - 25

Impact of the trend

Large particles of sewage cannot be effectively and so they provide a host for harmful pathogens, which increases the level of *E. coli*. Oil and grease from industrial effluent from the vegetable oil industries hampers the settling ability of sewage thereby resulting in large solid particles being discharged in treated water. Non-compliance with the TSS standard is indirectly associated with an increase in non-compliance with the standard of pathogens, *E. coli* and SRP.

2.3.3.6 AMMONIA

Ammonia is the pulse of an activated sludge wastewater treatment plant such as Darvill WW. Aeration is an important process and is directly affected by ammonia concentrations. Ammonia levels are therefore carefully monitored and controlled on a regular basis.

Trend and reasons for trend

Table 14 indicates a decrease from 100% compliance during 1993-1994 to 11.2-15.9 mg/l in 1994-1995 and rise to 10.3-11.4 mg/l from 1995-1996. The marginal deviation from the standard appears to have improved from 1994 to 1996. Reasons for this fluctuation are not exactly known, but industrial effluent seems to be the cause of reduced compliance. Studies conducted by de Haas (1996) prove that effluent containing excessive concentrations of oil and grease reduce compliance of TSS, SRP, pH and Ammonia.

TABLE 14: Trend indicating the margin of difference between the range of non-complying samples and standard Ammonia during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL mg/l	STANDARD mg/l
1993 - 1994	100% COMPLIANCE	0 - 10
1994 - 1995 OLD	NO RESULTS	0 - 10
FINAL	11.2 - 15.9	0 - 10
1995 - 1996 OLD	NO RESULTS	0 - 10
FINAL	10.3 - 11.4	0 - 10

Impact of trend

Ammonia is toxic and small concentrations may be harmful to aquatic life. Reduced compliance with the ammonia standard is linked to aeration problems and is associated with oily effluents of industrial origin. Ammonia concentrations are therefore carefully monitored and controlled on a regular basis. However when aeration is impaired due to industrial effluent problems, the operator can do nothing to avert the failure of nitrification.

2.3.3.7 CONDUCTIVITY

There is a consistent level of compliance with the conductivity standard. This is important as the aquatic life of the river will not be able to adapt very well to frequent change.

Trend and reasons for the trend

Table 15 indicates that conductivity decreased from 101 mSm⁻¹ during 1993-1994 to 85.3 mSm⁻¹ during 1994-1995 then increased to 89.7 mSm⁻¹ during 1995-1996. Reasons for this are blamed on industrial effluent however compliance with the conductivity standard is relatively high and has remained constant throughout the study. Pietermaritzburg in general does not have any conductivity problems. However, there have been a few problems with conductivity as a result of industrial effluent of poor quality.

TABLE 15: Trend indicating the margin of difference between the range of range of non-complying samples and standard Conductivity during 1993-1996

PERIOD	MARGINAL DIFFERENCE	
	ACTUAL mSm ⁻¹	STANDARD mSm ⁻¹
1993 - 1994	101	0 - 85
1994 - 1995 OLD	NO RESULTS	0 - 85
FINAL	85.3	0 - 85
1995 - 1996 OLD	NO RESULTS	0 - 85
FINAL	89.7	0 - 85

2.3.3.8 CHEMICAL MARGIN

This is the value of the sludge in monetary units divided by the cost of the chemicals used in the sewage treatment plant. A ratio above 1 means that the sludge is worth more than the cost of the chemicals. A value below 1 indicates that the chemicals cost more than the value of the sludge produced. The results at Darvill WWW indicate a constant figure of zero for the period of analysis.

Since the sludge produced at Darvill WWW is not economically valuable, it is not worth more than the chemicals that produce it. A large amount of capital is needed to produce sludge that is economically viable. But as already mentioned this is not economically feasible in the long run. An added dimension is that Darvill WWW relies heavily on biological processes thereby reducing the amount of chemicals required. This affects the analysis of attempting to value sludge in comparison to chemicals used.

2.3.3.9 SUMMARY AND CONCLUSIONS

The margin of *E. coli*, Chlorine, SRP, TSS, Conductivity, COD and Ammonia were analysed. Marginal difference is studied in an attempt to analyse those samples which do not comply with national standards. Chemical margin was also studied for the period between 1993-1996 (a comparison between the value of sludge produced and the cost of chemicals used to produce the sludge).

Results for non-complying samples of *E. coli* decreased from a maximum of 287 000 *E. coli*/100ml during 1993-1994 to 181 000 *E. coli*/100ml during 1994-1995, then increased to 340 000 *E. coli*/100ml during 1995-1996. SRP non-complying samples decreased from a maximum of 2 214 ug/l to a maximum of 1 730 ug/l then increased to a maximum of 3 720 ug/l. The COD decreased from 100% compliance during 1993-1994 to a range of 93.8-131 mg/l of oxygen during 1994-1995 then improved to 100% compliance during 1995-1996. The marginal value of non-complying samples of Chlorine decreased steadily from 6mg/l during 1993-1994 to 2.2mg/l during 1994-1995 to 1mg/l during 1995-1996.

The TSS trend showed an increased deviation of non-complying samples with a maximum value of 60.2 mg/l during 1993-1994, 136 mg/l during 1994-1995 and 174 mg/l during 1995-1996. Ammonia concentrations indicated 100% compliance during 1993-1994, increased maximum value of non-complying samples of 15.9 mg/l and a decreased maximum value of non-complying samples of 11.4 mg/l. Conductivity margin results decreased from 101 mSm⁻¹ during 1993-1994 to 85.3 mSm⁻¹ during 1994-1995 then increased to 89.7 mSm⁻¹ during 1994-1995. The chemical margin for all three periods was zero since sludge at Darvill WWWW has no value.

The marginal deviation of *E. coli*, SRP, COD and ammonia indicates increased maximum values of non-complying samples and a greater deviation from the standard from 1993-1995, then an improvement in non-complying samples for 1995-1996. Chlorine and TSS improved over the three-year period with reduced maximum values for samples not complying with the standard. This implies decreasing deviation from the standard.

The trends observed were difficult to interpret but according to Darvill WWWW management, improved compliance has been attributed to increased efficiency, while decreasing compliance is a result of poor industrial effluent particularly effluent containing large concentrations of SOG.

2.4 CONCLUSION OF CASE STUDY

The SDR method of analysis was used to analyse effectiveness, thrift and margin of Darvill WWWW during 1993 and 1996. Effectiveness is defined as the percentage of tested samples complying with the required standards in comparison to the total number of samples taken. Analysis of trends in *E. coli*, Chlorine, SRP, TSS, Conductivity, COD and Ammonia was used to calculate the effectiveness of the Works in treating wastewater. Increased compliance with standards set by DWAF indicates that treatment processes at the Works have become more effective from March 1993 to February 1996. However, not all the variables analysed produce the same trends.

E. coli and Ammonia data indicate a deterioration in compliance which is recognised as a problem and UW is aware of the need for improvement. Chlorine and TSS compliance increased, while the other variables decreased then increased in compliance. *E. coli* compliance decreased from 92% to 83% during 1993-1996. The SRP compliance fell from 92% during 1993-1994 to 87% during 1994-1995 and increased to 100% during 1995-1996, while COD fell from 100% to 96% then rose to 100% during this period. Chlorine and TSS compliance increased from 1.3% to 47% and 88% to 96% respectively during 1993-1996. Ammonia compliance results decreased from 100% during 1993-1994 to 92% during 1995-1996. A measure of conductivity indicates a constant trend of 98% compliance with standards.

Varying compliance levels are attributed to disturbances at the Works, this includes dealing with industrial effluent of poor quality. However management seems aware of this and attempts are being made to determine the source of problems. Large amounts of capital have been injected into the renovation and maintenance of the Works as shown by the thrift results. The service being provided by Darvill WWW has become more effective during the three-year study as is shown by increasing compliance with national standards. This is partly due to extensions and renovations. The capacity of the Works has greatly improved as a result of more capital input for extensions and new equipment.

Increased effectiveness of wastewater treatment protects the natural environment and the communities affected by treated water. Darvill WWW lacks effectiveness with regard to nutrient recycling but may change as alternative methods of sludge disposal are being considered. Effectiveness of nutrient recycling has remained constant at zero as no nutrient recycling takes place at Darvill WWW due to the costs involved but alternate methods of sludge disposal are being considered and this may change. In order to achieve a high percentage of compliance large capital demands are being placed on the Works. Increasing nominal asset value of the plant is noted during 1993-1996. Recent renovations have improved the overall effectiveness of the service being provided but the cost of doing this is investigated by the analysis of thrift trends.

Thrift is defined in terms of kilolitres of wastewater treated. The annual dry weather month of June, July and August were used to calculate the dry weather inflow based on the assumption that influent for these months excluded storm water and was composed largely of domestic and trade effluent.

Financial thrift, calculated as kilolitre of effluent per rand, has steadily decreased. The Works has become less thrifty in respect of capital. This is partly a result of increasing capital demands for extensions and renovations in the order of several million rands, to improve the capacity to deal with the deteriorating quality of effluent entering the Works. Problems with equipment and machinery have been caused large concentrations of SOG. Labour thrift calculated as kilolitres of wastewater treated per hour per year, appears to have increased during 1993-1996. This finding is inaccurate as casual labour is not included in the labour records of Darvill WWW. Contracted casual labour has increased. Casual labour hours are not included in the labour hours worked by the full time staff employed by UW therefore only permanent employees were considered during the analysis of labour thrift. Darvill WWW management indicates that labour demands since 1993 has increased with full time casual labourers increasing from none during 1993 to 6 during 1994 and 8 during 1995. It has been necessary to employ up to 20 additional casual workers on certain occasions. Casual labour is the preferred option in terms of human resource management as management avoids dealing with major human resource setbacks such as strikes. Financial costs are also reduced as the organisation no longer has to pay employee incentives and benefits. Additional casual labour is required for cleaning out tanks, cleaning the maturation river and overall maintenance. An approximate extra cost of R20 000 per month is required for extra labour. Problems due to poor trade effluent have been stated as the cause for extra labour.

Energy thrift, calculated as kilolitres of effluent per kilowatt hour, has drastically decreased. This is explained by the shift towards biological phosphate removal of wastewater. The use of new equipment and recent extensions appear to require a great deal of energy. The deteriorating quality of effluent made it necessary to improve the capacity of the Works. These renovations and improvements have increased the energy consumption of the plant. Chemical

thrift is calculated as kilolitres of effluent per rand of chemicals consumed. Since the biological process of phosphate removal is preferred, the use of chemicals has dropped substantially. The result has been an increase in chemical thrift which has compensated partly for the decrease in energy thrift. Reduced chemical usage is encouraged as this reduces the Conductivity of treated water and the demand on chemical resources. Operating costs also decrease.

Financial and energy thrift decreased while chemical and labour thrift increased. Increasing labour thrift is inaccurate since casual labour was not accounted for. Labour actually increased during the study as is indicated by increasing manpower costs. Chemical thrift increased due to increasing reliance on biological phosphate removal hence reduced chemical consumption. Decreasing financial and energy thrift is attributed to recent extensions and upgrading of the Works. Additional capital was required for the renovations and the improved technology appears to be consuming more energy. The decreasing financial, energy and labour thrift is indirectly linked to the poor quality of industrial effluent coming into the Works.

The margin is calculated for samples not complying with the standard, specifically the marginal difference of the range of non-complying samples with standards set by DWAF. Margin trends for *E. coli*, Chlorine, SRP, TSS, Conductivity, COD and Ammonia were assessed.

Non-complying samples of *E. coli* decreased from a maximum of 287 000 *E. coli*/ 100ml during 1993-1994 to 181 000 *E. coli*/ 100ml during 1994-1995, then increased to 340 000 *E. coli*/ 100ml during 1995-1996. The SRP non-complying samples fell from a maximum of 2 214 ug/l to a maximum of 1 730 ug/l then rose to a maximum of 3 720 ug/l, as did COD which decreased from 100% compliance during 1993-1994 to a range of 93.8-131 mg/l of oxygen during 1994-1995 then improved to 100% compliance during 1995-1996. The marginal value of non-complying samples of Chlorine fell steadily from 6mg/l during 1993-1994 to 2.2mg/l during 1994-1995 to 1mg/l during 1995-1996. The TSS trend showed greater deviation between non-complying samples and the standard with a maximum value of 60.2 mg/l during 1993-1994, 136 mg/l during 1994-1995 and 174 mg/l during 1995-1996.

Ammonia concentrations indicated 100% compliance during 1993-1994, increased maximum value of non-complying samples of 15.9 mg/l and a decreased maximum value of non-complying samples of 11.4 mg/l. Conductivity margin results decreased from 101 mSm⁻¹ during 1993-1994 to 85.3 mSm⁻¹ during 1994-1995 then increased to 89.7 mSm⁻¹ during 1994-1995. The chemical margin for all three periods was zero since sludge at Darvill WWW has no value.

For *E. coli* the general standard is 0 *E. coli*/100ml of sample, however, due to the problems that Darvill experiences, a special standard of 500 *E. coli*/100ml was given. Compliance with this standard was still a problem. Non-complying samples had *E. coli* concentrations that were far greater than the special standard. The marginal deviation of *E. coli*, SRP, COD and Ammonia indicates increased maximum values of non-complying samples and a greater deviation from the standard from 1993-1995, then an improvement in non-complying samples for 1995-1996. Chlorine and TSS improved over the three-year period with reduced maximum values for samples not complying with the standard. This implies decreasing deviation from the standard. Reasons for the trends observed are not clear but Darvill management states increased efficiency as the reason for improved compliance. Decreasing compliance seems to be the result of poor industrial effluent particularly effluent containing large concentrations of soap, oil and grease.

The analysis of Darvill WWW using SDR's produces varying trends in the measure of the key indicators. However an overview indicates that Darvill WWW is behaving in an environmentally sound manner even though increasing development and industrialisation is placing greater demands on the Works. The quality of industrial effluent seems to have a major impact on the performance of the Works. Although Darvill WWW is effectively treating wastewater, the costs of achieving compliance are increasing. Industrial effluent containing a large concentration of SOG in particular is a problem. This effluent has been traced to the vegetable oil industries.

Increasing costs of achieving compliance are indicated by decreasing financial, energy and labour thrift. At the moment, increased costs are being borne by the ratepayers of Pietermaritzburg, and UW. Polluters are being subsidised as the principle of the “polluter pays” is not enforced in the City. An integrated approach involving the Pietermaritzburg City Council, UW, DWAF and the vegetable oil industries is required to formulate a workable solution. The next chapter investigates the framework of proposed management options for managing the disposal of effluent from the vegetable oil industries.

CHAPTER THREE

FRAMEWORK OF PROPOSED MANAGEMENT OPTIONS FOR MANAGING INDUSTRIAL EFFLUENT FROM THE VEGETABLE OIL INDUSTRIES.

3.1 INTRODUCTION

Umgeni Water (UW) monitors water quality over the area extending from the Tugela to the Eastern Cape border. As part of Integrated Catchment Management, UW owns and operates Darvill WWTW in Pietermaritzburg and the Hammersdale Treatment Works near Durban. One of the functions of UW is the treatment of wastewater, including effluent from industrial processes which is discharged into the City sewers.

All industrial and domestic effluent within Pietermaritzburg that is discharged into the City's sewers is channelled to Darvill WWTW to be treated to acceptable legal concentrations before being discharged into the river system, as per the Water Act, 1956. Until 1992, Pietermaritzburg City Council owned and operated Darvill WWTW but UW took over the ownership and operation of the Works by financial agreement in May 1992. Together with the treatment of sewage, the responsibility for monitoring industrial effluent quality was delegated with the take-over of the Works. The Council now pays UW to treat industrial effluent. However in terms of local government, the legal power to formulate and enforce industrial effluent By-laws is the responsibility of the Municipality. It is envisaged by UW that it is necessary to apply the "polluter pays" principle to effluent disposal in the City. The current situation in Pietermaritzburg governing wet industrial effluent disposal is criticized by UW due to the inequity of the industrial effluent tariff, and inadequacies of the City drainage By-laws. Polluting industries are being subsidised by the ratepayers of the City.

Two important legal instruments are the Water Act which is enforced on a national level and the City By-laws together with an industrial effluent tariff which is the local control mechanism.

Another issue is the role of the City Council and UW for monitoring and control. The actions of and problems with the industries are also under investigation. The Department of Water Affairs and Forestry (DWAF) is responsible for national control. Problems with the disposal of wet industrial effluent became apparent in 1991 when DWAF closed effluent trenches at Darvill. Industries then became responsible for on-site treatment of effluent to acceptable concentrations before discharging to sewers or paying for wastes to be tankered to Durban or Johannesburg where co-disposal sites are available. The responsibility for effective disposal was shifted to the industrialist.

In order to produce an acceptable and sustainable solution to industrial effluent disposal, strong internal motivation (e.g. company environmental policies) or external motivation (strong local government to ensure compliance with By-laws to prevent illegal dumping or motivation through economic incentives) or both are necessary. As some industries do not have a strong internal environmental ethic and there may not be a strong local governmental ethic, problems have arisen with pollution and illegal dumping into the rivers as is the case with the local vegetable oil refining industries in the City. The current situation is one of traditional command and control but it seems that economic incentives should be considered as an option. Incentives such as marketable permits and pollution charges have worked as a self-regulatory mechanism in some European countries (Turner *et al*, 1994).

Problems have been identified with the regulation of industrial effluent disposal as highlighted by disturbances to Darvill WWW. The Works seems to be incurring higher costs as a result of deteriorating quality of industrial effluent. Effluent containing large concentrations of SOG fail to meet effluent standards. This results in major operation problems to the works and negative impacts to the environment. Within two months of UW's take over, a large tonnage of SOG was noticed entering the Works. The problem became progressively worse and the result is a series of management problems and increased costs of running Darvill WWW (see Chapter 2). Normal domestic sewage has a relatively small concentration of oil and grease, both as substances not in solution and in emulsified form.

Because a waterborne sewerage system produces a large volume of an aqueous suspension/solution of human waste (sewage), the treatment of sewage must obviously be by water-based methods. Large concentrations of oil and grease tend to affect the treatment processes (de Haas, 1996). This chapter investigates, problems being caused by industrial effluent from local vegetable oil refining industries, monitoring and regulatory instruments in place and proposed solutions to problems. National and local laws including the industrial effluent tariff are also studied. Alternate solutions are proposed on a local, provincial and a national scale. Various organisations involved include DWAF, UW, and the Pietermaritzburg City Council.

3.2 INTERESTED AND AFFECTED PARTIES

Stakeholders involved with problems related to discharge of industrial effluent from the vegetable oil industries can be divided into local, provincial and national categories.

Local affected parties include, the vegetable oil industries, Pietermaritzburg City Council, UW, ratepayers of Pietermaritzburg and downstream users. Provincial affected parties include, DWAF and downstream users, while national affected parties are DWAF, Department of Health and Department of Trade and Industry. This is indicated by Table 16. This study focuses on management options that can be used locally, so the effects on the Department of Trade and Industry and the Department of Health have not been thoroughly investigated. Management options focus on the involvement of the City Council, UW, DWAF and the vegetable oil industries.

TABLE 16: List of Interested and Affected parties.

LOCAL	PROVINCIAL	NATIONAL
VEGETABLE OIL INDUSTRIES	DEPARTMENT OF WATER AFFAIRS AND FORESTRY	DEPARTMENT OF WATER AFFAIRS AND FORESTRY
PMB CITY COUNCIL	UMGENI WATER	DEPARTMENT OF HEALTH
UMGENI WATER	DOWNSTREAM USERS	DEPARTMENT OF TRADE AND INDUSTRY
RATE PAYERS OF PIETERMARITZBURG	DOWNSTREAM ECOLOGY	DEPARTMENT OF ENVIRONMENT AFFAIRS AND TOURISM
DOWNSTREAM USERS AND AFFECTED RESIDENTS	INANDA DAM USERS	
DOWNSTREAM ECOLOGY		

3.2.1 VEGETABLE OIL INDUSTRIES

All industries in Pietermaritzburg are allowed to discharge industrial effluent into the sewers, provided that it meets the standards as dictated by the City drainage By-laws. As the vegetable oil refining industry is predominately a wet industry, most of the industrial effluent produced is discharged via the sewers and ends up at Darvill WWW. Problems at the works have been linked to the effluent from the vegetable oil industry which contains high concentrations of SOG. Apart from illegal concentrations of SOG in industrial effluent, the vegetable oil industries have also been found guilty of illegal dumping into the Baynespruit river (a tributary of the Msunduzi river that lies upstream from Darvill WWW). In practice it has been difficult to prosecute polluting industries although evidence in the form of photographs and results of samples of non-complying effluents have been taken.

It is not possible to give the exact number of vegetable oil product related discharges to Darvill WWT which have occurred over the years. Records are kept in the Control Room at Darvill WWT of incidences when insoluble (floating cream- or light brown coloured) oil is observed entering at the Inlet Works. These are only the observed cases and there may be more which were not observed, when the SOG is largely emulsified. The amount of oil is approximated on the basis of visual observation as “small”, “moderate” and “large” (or “very large”). During January 1993 -September 1996, operators recorded a total of 183 incidents of insoluble vegetable oil waste entering the Inlet Works. Large concentrations of oil and grease interfere with the treatment processes by producing a non-aqueous soluble phase which separates out at some point in the treatment chain. This affects the suspended or particulate component of sewage. Emulsions caused by the non-aqueous phase affect the treatment of the liquid component of sewage (de Haas, 1996).

The conditions dictated by the By-laws expect industries to perform primary on-site treatment to effluent that does not meet required discharge standards before it is actually discharged to the sewers. A recent study by UW indicates that the vegetable oil industries do not seem to engage in any effective primary treatment even though they produce effluent with high COD and SOG concentrations. Problems were identified with the effluent plant, dispatch area, margarine department and storm water management at the vegetable oil industries (Mashigo, 1996). The general comment was that all the vegetable oil industries in the area require ongoing maintenance and cleaning of areas that are and can be contaminated with oil and fats. Stormwater management also does not receive enough attention and the industries lack an environmental ethic and do not have any interest in waste management. These industries have shifted the responsibility of industrial waste management to someone else (Mashigo, 1996).

According to the current drainage By-laws, industries do not have any legal obligation for self-regulation through monitoring and metering of their effluent. Self-regulation often requires external motivation which can be achieved through economic incentives and technical support.

Some of these industries spend considerable sums on legal fees (industries have been involved in legal battles with UW when prosecution samples were taken) rather than monitoring and metering or improving their existing operations. Monitoring staff from Umgeni do not receive co-operation from these industries. Treatment of effluent from these industries is causing many problems to the owners and operators of Darvill WWW and to the City of Pietermaritzburg.

3.2.2 PIETERMARITZBURG CITY COUNCIL

This body is supposed to administer and control wastewater disposal by implementing drainage By-laws and an industrial effluent tariff. The City Council appears to be the most important regulatory body responsible for controlling the disposal of industrial and domestic effluent. However the system in operation is not very effective and both measures of control have proven to be ineffective as is shown by effluent quality problems experienced at the Works. Problems have arisen because regulation and legal control lie with the City Council but monitoring through effluent sampling and wastewater treatment is carried out by UW. The lack of an effective regulatory body makes it difficult to control illegal dumping and pollution of the sewers and rivers.

Waste management within the Greater Pietermaritzburg Area does not appear coordinated, and there is no regulatory authority responsible for ensuring that the required monitoring of facilities and operation standards are implemented. As a result the regulation of waste management facilities is ineffective. The whole regulation mechanism governing industrial waste disposal needs to be revised including a need for adequate regional forward planning to investigate the possibility a successful disposal site (Mander, 1995).

3.2.2.1 THE INDUSTRIAL EFFLUENT TARIFF

Pietermaritzburg City Council is responsible for implementing an industrial effluent tariff for discharging effluent into the sewers. This tariff is supposed to cover the cost of transporting and treating this effluent.

The estimation of the tariff makes an allowance of not charging industries for domestic wastewater and industrial processes which do not contribute to the final effluent. Industries are charged a tariff according to the oxygen absorption⁵ (OA) concentrations of wet effluent and the volume of freshwater consumed.

This tariff was developed by the City Council before Darvill WWW was bought by UW. The charge levied by the Council in respect of conveyance and treatment of industrial effluent discharged into its sewers from manufacturing premises is assessed using the current industrial effluent tariff formula, and until October 1996 was the following:

Where OA of industrial effluent is 70 or less, the charge per kilolitre of industrial effluent is 44 cents;

Where the OA of the industrial effluent exceeds 70, the charge in cents per kilolitre of industrial effluent shall be equal to

$$44c + \frac{[3.1 (OA-70)]}{100}$$

subject to a minimum charge which is currently R320 per six monthly period in respect of each manufacturing premises and where OA is measured in mg/l.

This tariff has many problems. It is not updated regularly to allow for factors such as inflation and improvements to the effectiveness and efficiency of the Darvill WWW. This tariff was last updated in 1992. The Pietermaritzburg trade effluent By-laws were drafted in 1953 and amended in the 1960's but have remained largely unchanged for the past three decades. The trade effluent tariff formula structure used in terms of the By-laws has also remained largely unchanged for at least the last twenty years. The factors used in the formula were revised on a periodic basis during the last twenty years.

⁵Oxygen absorbed refers to the measure of the oxygen demand in effluent or treated water. Oxygen absorbed is no longer recognised as the best measure of oxygen demand and it is recommended that Pietermaritzburg should consider measuring COD instead of OA.

Recent negotiations with the City Treasury and the City Engineers Department resulted in the current tariff being revised to:

$$55.0 + [3.9 \times (OA - 70)]$$

100

The revised tariff has been updated according to treatment costs (operating costs of Darvill WWW) and the percentage of incoming industrial effluent in comparison to total influent. The minimum tariff of 44 cents increased to 55 cents. The factor affecting OA increased from 3.1 to 3.9 while the baseline OA remained at 70. The minimum charge of R320 per six months increased to between R 421-R480 per six months.

The revised trade effluent assessment has been in effect since 1 October 1996. In addition to the above trade effluent tariff, industries in Pietermaritzburg also pay "sewerage rates" as a local tax similar to that which each household pays for sewerage. The sewerage rates are based on clean water consumption and are calculated on a sliding scale (decrease with increasing water consumption) which together with the maximum monthly rate indirectly encourages freshwater consumption (de Haas, 1997).

Industry does not pay for the "domestic wastewater" component in its effluent. An OA of 70 is taken as the maximum OA value of domestic wastewater. Therefore, industries only pay for OA concentrations over a value of 70. The OA value for an industry is based on the worst sample, in terms of OA, out of at least six samples of effluent taken over a six month period.

The current tariff formula needs to be reassessed because:

- it does not correctly reflect the industrial load received at the Darvill WWW;
- the basic charge is considered to be inadequate to cover the cost of wastewater treated per unit volume;
- the charge to industries is based on estimated effluent volumes and the OA component, which only reflects easily oxidisable organic material and not the more expensive processes needed to treat and dispose of solid, inorganic waste and phosphates.

Use of the OA component alone often does not capture the actual content and contamination of some industrial waste. The single biggest problem with the old industrial effluent tariff is its relative insensitivity to OA. OA is not recognised as the best measure of effluent strength and neighbouring City Councils have found that a measure of COD is more effective since COD is a more sensitive test and can be readily related to oxygen demand in activated sludge treatment processes for sewage (process used at Darvill WWW);

- it does not include a real cost for conveyancing (sewer capital, maintenance, renewal costs for pipes and infrastructure but it does have a conveyancing component which is the basic charge per kilolitre of wastewater treated.

de Haas (1996), shows why the current tariff is not effective, figure 21. Since the treatment costs for wastewater are mainly a direct function of load⁶, in terms of industrial effluent it would be equitable for twenty (used for illustrative purposes) high strength⁷ industries to collectively pay **24%** of the operating costs of the Works via an industrial effluent formula. However, according to the PMB industrial effluent formula, industries are paying only **3%** of the total operating costs of Darvill. To this may be added the amounts paid as “sewerage rates”, which recovers a further **4%** from the “top twenty industries” identified. Combining the two revenue sources (industrial effluent tariff and sewerage rates) gives a recovery of about **R120 000** per month from the “top twenty” industries. Using the proposed load allocation tariff (based on a total of **24 %** OA load contribution by these industries), the equitable recovery should be about **R400 000** per month, leaving a shortfall of about **R280 000** per month. This shortfall is currently being made up by domestic users and other ratepayers via the monthly sewerage levy and/or annual rates (de Haas, 1996).

⁶Load refers to the specific quantification of material in the effluent, and not merely to volume. Load in mass units = flow (volume) x concentration (mg/l)

⁷High strength-This refers to the load and not to the volume of effluent. High strength industries are responsible for a greater COD load even though the volume may not be excessive.

While the burden per household per month is a few rands, polluters need to internalise their costs and that downstream users (which includes the environment and people) should not be expected to suffer the costs.



Figure 21 Comparison between the old tariff and a new load based tariff. Source: de Haas, 1996

3.2.2.2 THE DRAINAGE BY-LAWS

Direct control over the discharge of industrial effluent is contained in national and local legislation where provision is made for industries to discharge their effluent into sewers but the effluent must conform to the standards set by local authorities in the local By-laws under the Water Act. It is illegal for industries to discharge industrial effluent in any other way that would result in pollution of any private or public water. The current situation in Pietermaritzburg shows lack of enforcement as is evident from the recent increase in the number of prosecutions with respect to illegal dumping.

Section 2 of the Pietermaritzburg-Msunduzi Transitional Local Council's By-laws refer to industrial effluent. *No person shall discharge or cause or permit to be discharged into any sewer any industrial effluent not meeting the effluent standards as prescribed in the By-laws without first having obtained the written permission of the City Engineer in terms of section 7 or, if such a permit has been obtained, otherwise than in accordance with any and all such conditions attached to such permits.*

Section 7 (7) states that where tests are to be carried out for the purposes of an application for a permit, the costs incurred in carrying out such tests shall be borne by the applicant. The limit for acceptable discharge of total soaps, oils and grease (SOG) of vegetable origin is 50 mg/l.

Table 17 compares the accepted standard for SOG in Pietermaritzburg and other cities. The drainage By-laws as dictated by the City Council give acceptable standards of indicators that determine quality. Pietermaritzburg has a problem with industrial effluent containing large concentrations of SOG hence the higher standard in comparison with neighbouring Cities. Pietermaritzburg has a limit of zero for mineral oils and grease and 50mg/l for vegetable oils, fats or waxes while, other Cities have a maximum limit between 20mg/l and 500mg/l for mineral oils and grease and 250mg/l and 500mg/l for vegetable oils, fats or waxes.

It has been extremely difficult to successfully prosecute industries that have breached national and/or local legislation and the fines imposed in successful cases have been minimal and largely ineffective. In terms of the local drainage By-laws it has been difficult to convict any particular industry. Prosecutions are delayed as a result of limitations imposed by the legal system. However, a recent case against an offending company was prepared by UW which resulted in the company admitting guilt. Although the settlement amount was small, this case was perceived by UW to be a major achievement in terms of publicity gained by the company's admission of guilt. The company has since entered into an agreement with UW, which would result in them cleaning up their waste to meet the local By-law standards. The drainage By-laws also fail to enforce any systems of compulsory pretreatment of wastewater at a primary treatment plant on the site of the industry.

Standard values of certain components are also not adhered to and are not accounted for by the tariff. The monitoring of effluent and taking of samples are not clearly defined in the drainage By-laws. Current Pietermaritzburg By-laws seem to be ineffective in regulating the discharge of industrial effluent into the sewers. There is no apparent provision for regulating effluent except for the tariff and By-laws. It seems that the Council is wary of implementing more stringent pollution control measures as this may discourage industries from investing in the City.

TABLE17: Comparison of accepted standards for SOAP, OIL and GREASE in Pietermaritzburg and other Cities.

Town/ City	Parameter	Limit (Units)
Pietermaritzburg	<ul style="list-style-type: none"> • Mineral oils and grease • Vegetable oils, fats or waxes 	<p style="text-align: center;">nil</p> <p style="text-align: right;">50 mg/l</p>
Durban	<ul style="list-style-type: none"> • Oils greases or waxes of mineral origin • Vegetable oil, fats, grease and waxes 	<p style="text-align: right;">50 mg/l</p> <p style="text-align: right;">250 mg/l</p>
Amanzimtoti	<ul style="list-style-type: none"> • Oils greases or waxes of mineral origin • Vegetable oil, fats, grease and waxes 	<p style="text-align: right;">20 mg/l</p> <p style="text-align: right;">200 mg/l</p>
Pinetown	<ul style="list-style-type: none"> • Grease and mineral oil, tar and tar oils not dissolved • Animal and vegetable oils and fats 	<p style="text-align: right;">20mg/l</p> <p style="text-align: right;">200 mg/l</p>
New Germany	<ul style="list-style-type: none"> • Substances not in solution (including fat, oil, grease, waxes and like substances) • Substances soluble in petroleum ether 	<p style="text-align: right;">500 mg/l</p> <p style="text-align: right;">250 mg/l</p>
Hammarisdale	<ul style="list-style-type: none"> • Substances soluble in petroleum ether 	<p style="text-align: right;">250 mg/l</p>

Source: de Haas, 1996

3.2.3 UMGENI WATER

Since May 1992 UW has been operating Darvill WWW and is responsible for treating all wastewater that enters the Works. UW also monitors wet industrial effluent and calculates the industrial effluent tariff. However the City Council still acts as the controlling body. Through routine sampling UW is able to monitor wet industrial effluent from all industries in the area. OResults of these samples are used to calculate the tariff. As UW is also responsible for the operation of the Works, it is also their duty to adequately treat wastewater before it is discharged into the Msunduzi River. The quality of influent to Darvill WWW therefore impacts on the operating capacity of the Works, thereby affecting the efficiency.

Darvill WWW cannot cope with high quantities of oil and fat which obstruct the wastewater treatment processes by blocking the supply of oxygen needed for biological treatment of the wastewater and by physically blocking up the pumps and pipes. Solids in wastewater adheres to the oils and fats, thereby hindering the sedimentation process. The estimated amount of insoluble oil/ grease discharged over an 8 month period during January 1996 and August 1996 was of the order of 300 metric tons. It is common for one discharge incident to amount to about **2.5 metric tons**. The amount of emulsified oil discharged is unknown, but may be of a similar order (de Haas, 1996).

It is not possible to physically observe emulsified oil in the influent wastewater. Sometimes a small amount of insoluble oil accompanies the emulsified fraction in the wastewater. Emulsified (as well as insoluble) oil can only be accurately determined by analysis for oil and grease using solvent extraction and gravimetric techniques (mass measurements). This method is time consuming and requires technician training; it is not used routinely for the influent wastewater by the Operations staff due to the time delay between doing an analysis and getting a result (one day) compared to the liquid retention time in the treatment plant (less than one day). Moreover, there is a delay of one to two hours from the time the oily waste is discharged by a factory in the Willowton area and when it reaches Darvill WWW, so it is not easy to carry out an inspection at the plant and find the guilty party discharging oily waste to the sewer.

The total budgeted cost for Darvill WWT in the 1995/6 financial year was R19.8 million. This figure is based on the agreement reached with the City Council in 1992 and includes operating costs, capital costs associated with the original purchase price in 1992, and additional capital expenditure agreed upon in 1992, plus interest and redemption. Clean up costs at Darvill WWT are difficult to estimate accurately, especially where full-time labourers may be used for another task but are assigned to clean up the SOG. This leads to under-estimating the costs. Approximate costs can be defined at R20 000 per month (excluding capital costs due to diminished plant capacity). During some months in the past, attempts were made to use an outside contractor to remove the scum, oil and grease from the various tanks. The contractor's costs did not include transport costs to dump the removed waste in the Darvill screenings trenches. The contractor's bill to UW was R6600 for an attempted clean-up over two days in June 1992; and R12 600 for clean-up over three days in September 1992. This was not a cost-effective nor technically effective alternative (de Haas, 1996).

Umgeni Water is responsible for monitoring offending industrial effluent discharge, but the current system does not allow for effective regulation. Although the By-laws demand that industrial companies obtain permits to discharge waste into the public sewers, these are easily obtained and do not sufficiently regulate the content of the effluent. Industries do not include complete details of the waste products that they produce, in their inventories. It is not always easy to obtain monitoring samples from an industry. Samples are required to accurately calculate an industry's OA component and assess the nature of the effluent with regard to the drainage By-laws. Grab sampling occurs when samples are taken on unscheduled runs due to the lack of co-operation from the industries. This results in an increase in the number of prosecution samples which are used in court cases against the industries.

There is some uncertainty between the City Council and UW about their responsibilities in relation to industrial effluent. The Council seems to believe that it is only responsible for managing the sewer infrastructure and that UW is responsible for all matters related to the treatment of the effluent.

UW's position is that they are only responsible for the monitoring, control and management of effluent treatment according to policies and regulations set by the Council and that amending the tariff and dealing with illegal discharges to the sewers are the Council's responsibility. UW is involved in a number of related issues with regard to water in this area. It is responsible for the bulk water supply, wastewater treatment; internal environmental management; catchment management; external environmental monitoring and acting as agents of DWAF. Their responsibility as bulk water suppliers means that they are responsible for treating freshwater supplies to Pietermaritzburg and Durban. As a result the quality of Msunduzi river impacts a great deal on their ability to treat this water. They have a vested interest in water quality of Msunduzi river and are responsible for discharging into the river.

The City Council pays UW to treat wastewater hence they work for the Council and do not have the authority to regulate industrial effluent disposal. UW requires an effective internal monitoring system for assessment of influent and the discharge of treated water. There is no designate pollution monitor at Darvill WWW but treated water is assessed according to local and national standards hence no single body is responsible for disturbances to the Works. As a result, problems are often not given immediate attention and disturbances escalate.

Due to their involvement in catchment management and as agents of DWAF, UW has the task of monitoring its own activities. UW also has an economic interest due to the cost of operating Darvill WWW and an environmental interest due to their involvement in catchment management and as agents of DWAF.

3.2.4 THE RATEPAYERS OF PIETERMARITZBURG

Due to the structure of the industrial effluent tariff most of the cost of treating industrial effluent is being subsidised by the City Council (ratepayers). According to the industrial effluent tariff, industries only pay 3% of the total operating costs for wastewater treatment even though they are responsible for 24% of the total load and 6% of the volume. Industrial effluent has high strength even though it is low volume while domestic effluent is high volume and low strength and constitutes 94% of the volume and 76% of the load.

Industrial effluent treatment is being subsidised by the ratepayers. If the principle of the “polluter pays” is to be fully adopted, industries should be paying more for the treatment of their wastes (true cost of treating their effluent).

3.2.5 DOWNSTREAM USERS AND AFFECTED RESIDENTS

Downstream users include local communities and communities from surrounding areas.

Downstream ecology is also affected by illegal discharges and inadequately treated wastewater. The Msunduzi river forms a part of the Inanda drainage basin hence the supply of water from Inanda Dam is affected by the quality of treated wastewater discharged from Darvill WWT. Those communities (sociological and ecological) relying on the Msunduzi river are affected.

The quality of industrial effluent impacts on the wastewater treatment plant as well as on downstream users. There are several informal settlements along the Msunduzi river, downstream of Darvill WWT and at Inanda Dam. The residents of these settlements are dependant on water from the Msunduzi river for a supply of drinking, bathing and irrigation water. There is no current data to prove that users of the Msunduzi downstream of Darvill WWT are being negatively affected by the quality of treated effluent that is discharged to the river. Further investigations are required to determine the effects of the river on downstream users. Downstream users reliant on the river for drinking bathing and irrigation water may be exposed to health risks caused by high *E. coli* concentrations.

Dickens and Graham (1996) indicate that the quality of the Msunduzi supplying Inanda Dam meets the standard requirements except for *E. coli* and SRP. This non-compliance may be attributed to activities taking place upstream, including discharges from Darvill WWT and illegal dumping into the Baynespruit. Further investigations are required to determine the actual cause of this non-compliance. The ecology forms a part of downstream communities that are affected. Various indicators are monitored on a regular basis to determine the quality of treated effluent. Chapter two indicates that effluent containing high concentrations of SOG have led to problems of non-compliance with *E. coli*, SRP, Ammonia and COD standards.

Routine samples of discharged water indicate that the Works is failing to meet certain DWAF standards. Non-compliance of important indicators such as *E. coli* and SRP have been linked to incidences of excessive oil pollution. Although the immediate effects on the efficiency of the Works does not appear severe the long term effects of prolonged non-compliance could result in irreparable damage.

Since the Msunduzi river is a tributary to the Umgeni river, which flows into the Inanda Dam, the quality of the river contributes to the water treatment and purification processes. The quality of water affects the amount and cost of chemicals required for treating water at Inanda dam. Eutrophication (the enrichment of water with plant nutrients such as nitrate and phosphate) of the dam is also affected hence the river ecosystem is affected. Currently, treated effluent from the Darvill WWT contributes approximately 30% of the phosphate load to Inanda Dam and a significant contribution to the *E. coli* level found in the Msunduzi river. According to report S 9.22/WQMSAP (1996), the Msunduzi river just below the Works was given a Class E (unsatisfactory) grading while the river entering Inanda Dam was graded Class C (satisfactory). The Baynespruit river which lies upstream of the Works exceeded the *E. coli* count in order of 10 000/100ml compared to the special standard of 500/100ml. Sewer problems among other sources such as the illegal discharges from the industries have been found to be the cause of this Ammonia concentration of the Msunduzi downstream of Darvill WWT exceeded the standard of 0.2mg/l and the SRP concentration was also high.

The distance of the Msunduzi river between the Works and Inanda Dam gives the river sufficient time for water quality to improve before reaching the dam. Although this is the case, the quality of the water in the Msunduzi does impact significantly on treatment costs of Durban Heights and Wiggins as these are water care works which are found downstream of Darvill. Therefore the quality of water that the Inanda dam users receive is also affected. It is likely that prolonged deterioration in water quality will increase treatment costs for water from Inanda dam.

3.2.6 DEPARTMENT OF WATER AFFAIRS

The most important single piece of national legislation relating to water conservation in Pietermaritzburg is the Water Act 54 of 1956 as amended which includes the regulation of water pollution in South Africa. DWAF is the most important national regulatory body controlling the quality of treated wastewater discharged from the Works. National laws are laid down by DWAF. The quality of treated water is controlled by setting general standards for normal conditions and special standards for unusual circumstances. These standards are only enforced for treated water that is discharged to the rivers and not effluent discharged to the sewer.

Currently industries can move from areas in South Africa where pollution control is relatively stringent to areas where it is less so in order to avoid paying higher costs as there are no national pollution control policies or regulations applying to industrial effluent discharge to municipal sewers. DWAF has national control which it can use to regulate this behaviour thereby promoting uniform regulation in all cities in the country. Pietermaritzburg City Council does not want to discourage economic development in favour of promoting environmental preservation hence pollution control in the City is not very effective.

The Water Act, in common with water pollution control legislation in most developed countries of the world, does not require the water authority to ensure that the quality of marine and fresh water resources should remain in a pristine state unless this can be justified for the purpose of meeting the requirements of one of the recognised water uses (DWAF, 1991). Drinking, bathing and irrigation water of the Msunduzi river is being affected by pollution from the vegetable oil industries but DWAF does not appear to be adequately involved.

Although UW acts as an agent for DWAF in terms of the Water Act, prosecution of offending polluters under national legislation such as the Water Act is carried out by the DWAF. However, UW can proceed with private prosecutions if an offence has occurred in terms of the local By-laws.

Section 21 of the Act states, in part, *that any person using water for industrial purposes is required to purify or otherwise treat the water used and any effluent produced by or resulting from its use, in accordance with specified effluent standards. However, discharge of industrial effluent into a sewer of a local authority is not subject to these provisions because, following acceptance of the effluent into the sewer, the onus for suitable treatment then falls upon the local authority.* Section 22 states, in part, *that people that have control over land shall prevent any public or private water on or under the land including rain water from being polluted or further polluted by any solid liquid or gaseous substance capable of causing water pollution.* Section 23 contains a general prohibition on water pollution. It states, in part, *that any person shall be guilty of an offence if they wilfully or negligently pollute any public or private water so as to render it less fit for; the purposes for which it is or could be ordinarily used, the propagation of fish and other aquatic life, recreation or other legitimate purposes.*

This general prohibition does not apply to any act performed in accordance with section 21 or 22. Pollution is only defined in general terms as in section 23, there is no formal definition of pollution and there is a statutory presumption of intention or negligence.

Environmental and financial issues are becoming increasingly complex. Nevertheless, justification of limited environmental degradation on the basis of financial considerations is rapidly becoming unacceptable. DWAF recognises this but individual, regional and national financial objectives are important considerations in reaching water quality management and pollution control decisions (DWAF, 1991). This causes complications with policies and strategies that are introduced by DWAF.

3.3 PROPOSED SOLUTIONS FOR HANDLING VEGETABLE OIL EFFLUENT IN PIETERMARITZBURG

Proposed solutions are investigated with respect to the involvement of interested and affected parties. Alternatives include on-site treatment for effluent from the vegetable oil industries, a further revised industrial effluent tariff and drainage By-laws, revised national legislation and the use of economic incentives. Self-regulation via incentives such as marketable permits is compared to governmental command and control which has been enforced thus far. Another important aspect is the lack of communication and the urgent need for a forum of interested and affected parties.

3.3.1 VEGETABLE OIL INDUSTRIES

Problems being experienced with the vegetable oil industries highlight the need for industries to be made aware of environmental and economic consequences of their actions and develop stronger environmental ethics. A stricter legal system or stricter enforcement could be developed in order to encourage industries to adopt more ethical and environmentally sound practices. Clean technology refers to environmentally acceptable activities that are being adopted globally and it is those techniques, processes, and products that avoid or diminish environmental damage and/or the usage of natural resources and energy (Jackson, 1993).

There are examples in Europe and North America of industries implementing clean technology including the paint and metal plating industries. Both of these industries produce large amounts of wet industrial effluent. An investigation into cleaner technologies includes an analysis of technological opportunities (availability of technology), the costs for developing new technologies and the time for adopting the new innovation (Opschoor, *et al*, 1994). On-site treatment has been investigated below as one option of clean technology for the vegetable oil industries. The derived product from treatment such as sludge and disposal of industrial effluent constitutes pollution and industries can choose to either treat the effluent on-site, reduce the volume of effluent through improved technology, discharge to sewers and pay a more equitable tariff or pay other organisations to treat the effluent.

3.3.1.1 ON-SITE TREATMENT (PRIMARY TREATMENT AND OR RECYCLING) FOR THE VEGETABLE OIL INDUSTRIES

One method of treatment is the option that treats slurry to produce a concentrated waste. This method results in a recyclable water component and a solid waste component. After the effluent is converted into a slurry and both the emulsified oil and dissolved solids are removed, the resulting water component can either be reused or discharged to the sewers. Solid waste should then be disposed of by legal and ethical means. According to Ramlall (1997), this method is estimated to cost, between 3 and 4 million rands to set up and approximately R 500 000 per annum to operate. Chemicals required are sulphuric acid, caustic or lime. All necessary technology for this method is available locally and it would not be a problem to obtain this equipment. This method of primary treatment is currently being used in South Africa and it appears very likely that it will also work in Pietermaritzburg but it is unlikely that the vegetable oil industries will accept this option due to the excessive costs involved. (Ramlall, 1997 *pers. comm.*) The principle of "batneec" (best available technology, not entailing excessive cost) is recommended as the best alternative of promoting primary treatment of effluent. Other options have also been identified by consultants.

3.3.1.1.1 COST

According to Grous (1996), the approximate cost of establishing a primary treatment plant is between R100 000 and R500 000 depending on the budget and interests of industries. Management of different industries have differing attitudes hence they have different needs for on-site treatment plants. The vegetable oil industries in Pietermaritzburg in particular are not interested in developing a sustainable treatment plant as their main concern is to commission a system that will temporarily satisfy UW (Grous, 1996 *pers. comm.*). The costs estimated are given for a single firm.

3.3.1.1.2 PLANT OPTIONS

Three methods of primary treatment for the vegetable oil industries have been identified: physical-chemical, solvent extraction and a method involving effluent concentration, evaporation and distillation (Grous, 1996 *pers. comm.*). The advantage of these methods is that they are designed to be less labour intensive and run almost independent of full time technicians. Operators are required to respond to disturbances but there is no need for a full time engineer or a technician and long term maintenance of such plants is inexpensive. These treatment options reduce the oil content of the effluent to acceptable discharge levels, reduce the quantity and quality of effluent to concentrations that are economically feasible and reduce raw materials and freshwater demand.

PHYSICAL-CHEMICAL METHOD

This method uses specialised chemical flocculants to precipitate dissolved solids and produce colloidal particles and also allows for recycling effluent so that a percentage of raw materials can be recovered. The extraction of the colloids reduces the SOG component of the effluent making it possible to achieve the required standard of 50 ppm.

The primary method of refining vegetable oil involves heating crude oil then acidifying. This stripping of crude oil results in an interface layer that contains recyclable oil. Large amounts of caustic are required for neutralising this acidified component. This produces an alkaline effluent which can be used to neutralise acidic effluent. When both these effluents are combined it will result in the separation of acidic particles and the oil will separate from water. The oil particles can then be removed through gravitational or floatation processes which also reduces the SOG level of the effluent.

This method reduces the COD concentrations of the effluent significantly. The added advantage is the ability to recycle raw materials and reducing the quantity of industrial effluent. It is possible to recycle water thereby reducing the freshwater consumption.

SOLVENT EXTRACTION METHOD

This method involves the extraction of oil and grease from effluent using hexane and the possibility for recycling exists but the costs and chemical requirements of this method are higher. The use of hexane as a solvent also creates a few problems as technicians will need to be adequately trained to handle, store and dispose of the solvent.

EVAPORATION AND DISTILLATION METHOD

This method involves mixing effluents from the neutralisation, margarine, acid, and centrifuge plants. Primary oil is recovered at low pH and the remaining effluent is concentrated through evaporation. The water distillate is treated with activated carbon and recycled to the plant. The remaining organic sludge component is sent to the boilers for combustion where gas emissions of carbon dioxide and carbon monoxide is produced. The advantage of this method is that industrial effluent is disposed of in a method that is environmentally sound since the overall by-products are gases which are also found in the atmosphere. The disadvantage however is a large energy requirement.

3.3.1.1.3 REQUIRED PERIOD FOR ESTABLISHING ON-SITE TREATMENT PLANTS

The average minimum period required to establish a treatment plant is between three and six months. This depends on the complexity of the plant, the availability of manpower and equipment. Most of the equipment required for these treatment options have to be imported as South Africa is not familiar with clean production strategies (Grous, 1996 *pers. comm.*).

3.3.1.1.4 EXISTING FACILITIES

Fundamentally some of the oil industries do have primary effluent treatment plants and storage and neutralising tanks. Some of these treatment plants have minor limitations while others are completely ineffective. Mashigo (1996) highlighted the following aspects of these facilities:

- No capable personnel are assigned to effluent and general waste management.
- The effluent plant capacity seems inadequate at some of these industries.
- The overall condition of the effluent is poor and samples collected from certain effluent lines showed non-compliance with the drainage By-laws.
- Effluent monitoring programmes and quality control mechanisms are inadequate.
- Progress on new effluent plants are halted due administrative and staff problems.

3.3.1.2. TREATMENT BY OTHER ORGANISATIONS

Waste treatment organisations such as Waste Tech can be paid for waste disposal. Industries can choose to pay for effluent to be tankered and disposed of at registered co-disposal sites as was the practice a few years ago (de Haas, 1996). The cost implications of this are greater.

3.3.2 PIETERMARITZBURG CITY COUNCIL

The City Council as the regulating body responsible for the implementation of an effective industrial tariff and drainage By-laws. The Council is also in the position to investigate the possibility of establishing a City disposal site for industrial effluent.

3.3.2.1 ESTABLISHING A CITY DISPOSAL SITE FOR INDUSTRIAL EFFLUENT

Together with amendments to the drainage By-laws and the industrial effluent tariff, the City Council needs to consider the option of providing facilities for a liquid waste disposal site. The New England landfill site was developed as a municipal site in 1952. At this time no environmental controls were required for landfill sites. The site has accepted both domestic waste and industrial effluents and sludges. These wastes were land farmed at the Darvill WWW trenches until 1991 when DWAF disallowed this practice. A number of incidents of illegal dumping and discharging to sewer and stormwater drains followed. Due to concerns about the potential for ground water leaching and surface run off into the Msunduzi, this site is no longer deemed acceptable as it stands (Mander, 1995).

According to Mander (1995), an assessment that was undertaken by Lombard in 1991 indicated the presence of leachate seepage zones over the old meanders of the river where land filling had taken place, also elevated concentrations of dissolved solids, nitrogen, sodium, iron and aluminium were shown. These results indicated that the site should be sealed and the leachate controlled. It was argued that once the rehabilitation of the site had been achieved, the life of the landfill site could be extended by sealing the existing site and extending it vertically to create further airspace. A three-phase approach was recommended for using the New England Landfill site. First the rehabilitation and vertical extension of the existing landfill which will add 15-18 years to the site. The second and third phases entail extending the existing landfill site along the floodplain of the Msunduzi river and the Blackburrowspruit towards Darvill WWW. The planned extensions will add another 18-20 years to the life-span of the site. A permit has subsequently been granted to the Pietermaritzburg City Council for the existing operation and extension of the New England landfill site as a Class II sanitary landfill site (Mander, 1995).

Various options for more advanced sludge treatment and disposal at Darvill WWW include:

- Co-disposal with domestic refuse at the local landfill situated on New England Road;
- High lime process after transporting by rail outside the City;
- Composting and transporting the product to the City perimeter or beyond;
- Thermal drying and transporting to the dried product to the City perimeter or beyond;
- Incineration and transporting the ash to the City perimeter or beyond (de Haas, 1997).

The first and second options are fairly simple options while fourth and fifth options are more advanced. The high lime study is based on a desk study for a hypothetical plant in the North West Province and has not been used to date in South Africa. Thermal drying is being introduced to a sewage plant in Cape Town for the first time in this country. The success of these methods is uncertain in this country and incineration is much more expensive compared to the other options. Therefore composting appears to be a more likely option (de Haas, 1997). These options are based on the notion that primary on-site treatment will result in sludge being produced.

3.3.2.2 INDUSTRIAL EFFLUENT TARIFF

As outlined the tariff structure imposed by the Council in Pietermaritzburg does not meet the costs of treating the effluent released by industry. Table 18 shows the tariffs charged by the Pietermaritzburg Council compared to other areas. Pietermaritzburg's industrial effluent tariff is extremely low when compared to other towns and cities and provides little financial incentive for industries to minimize the (organic) strength of their effluent. At present in Durban the principle which is applied to the treatment of effluent is that the costs of such treatment must be covered. It is estimated that the average cost for treating effluent per kilolitre is 86 cents in Durban. This is just under twice that being charged by the Pietermaritzburg Council (Graham, 1996 *pers. comm.*).

TABLE 18: Comparison of industrial effluent tariff for Pietermaritzburg (PMB) and other cities/towns, based on 1995 data. OA and settleable solids' concentrations are estimates for comparative purposes only (Conveyance component of tariff given in parentheses).

Effluent Strength	O.A (mg/l)	SS (ml/l)	City A (c/kl)	City B (c/kl)	Town C (c/kl)	Town D (c/kl)	PMB (c/kl)
Low	100	14	57 (27.5)	137 to 146 (59)	81 (32)	488 (142)	45 (44)
Medium	500	50	154 (27.5)	450 to 493 (59)	222 (32)	1868 (142)	57 (44)
High	1000	100	280 (27.5)	842 to 929 (59)	492 (32)	3595 (142)	73 (44)
Industrial effluent Volume (MI / month)			933	220	182	6.9	168

Source: Umgeni Water (1996)

The industrial effluent tariff needs to be adapted to develop a more equitable approach to apportioning the burden of the treatment costs. The situation can be improved by restructuring and regularly updating the tariff as described above.

The industrial effluent tariff formula should be changed so that it is based on actual costs and could include:

- the cost of treating those substances that are not covered by the OA component, for example SOG and phosphates, suspended solids and other inorganic chemical contamination;
- inspection and monitoring charges;
- provision for inflation;
- implementation of new treatment technology.

However, any restructuring of the industrial effluent tariff formula must trade-off benefits lost if industries withdrew from the Pietermaritzburg area. The withdrawal of industries could have detrimental economic effects in an area where unemployment and continued development are already matters of concern. Increases in tariffs will also result in increased costs to the environment due to illegal discharges to the river systems if not properly monitored and enforced. Figure 22 illustrates the comparison of costs based on the old industrial effluent tariff and an *ideal* tariff (appendix C) where the total costs to Darvill WWW are recovered from twenty major industrial effluent producers in the City in the same proportion as their OA load to the Works (24%) (de Haas, 1996).

Figure 23 estimates costs to individual industries in the “Top Twenty” industrial effluent producer group, for two scenarios: the existing (old) industrial tariff; and an *ideal* tariff with full cost recovery based on the 24% load contribution to Darvill WWW. Some of the industries would *not* pay significantly more, because the artificial system of charging on maximum OA recorded in the six-month assessment period as currently used would fall away. On the other hand, Figure 23 shows that certain industries would pay *up to six or nine times more* because they have a high strength effluent (produce a significant load of organic material in their industrial effluent).

The new tariff better promotes the “polluter pays” principle. Rather than pay such large amounts, those industries which produce high loads will probably find it more economical to treat their effluent at the source, and perhaps to recover valuable material from the effluent in the form of a by-product.

What it means in R/c Averages	
<u>Old PMB Tariff & Sewerage Rates</u>	<u>Proposed OA load allocation (24%)</u>
<u>Twenty industries</u>	<u>Twenty industries</u>
R 1.28/kl	R 4.40/kl
R 8.41/kg OA	R 29.00/kg OA
Total R 120 000/ mo.	Total R 400 000/ mo.
<u>Domestic/ other</u>	<u>Domestic/ other</u>
R 0.88/kl	R 0.72/kl
R 35.93/kg OA	R 29.36/kg OA
Total R 1.53 million/mo.	Total R 1.25 million/mo.

Figure 22 Comparison between the old tariff and an *ideal* tariff Source: de Haas, 1996

Clearly, a phased approach would be needed if the *ideal* policy of full cost recovery on a load basis were to be implemented, since it may be unreasonable to ask a single industry to increase its monthly industrial effluent costs from around **R9000** to **R85 000** per month at short notice. The equitable recovery should be about **R400 000** per month, leaving a shortfall of about **R280 000** per month. This shortfall is currently being made up by the domestic/ other ratepayers via the monthly sewerage levy and/or annual rates.

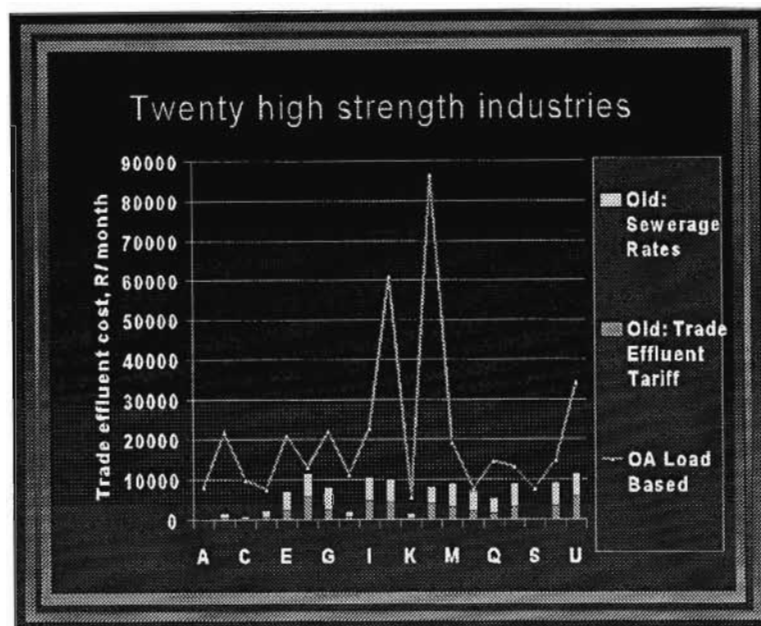


Figure 23 Estimation of costs for twenty high strength industries. Source: de Haas, 1996

3.3.2.2.1 REQUIREMENTS FOR A MORE EQUITABLE INDUSTRIAL EFFLUENT TARIFF

A new tariff will need to take the following into account: sewage rates, conveyancing and treatment penalties. Rates should be included in the new tariff so that only one charge is made to the industries, conveyancing charges are for installation and maintenance of the reticulation system and treatment penalties will include variables which have an important impact on the treatment process.

A new and more equitable tariff which includes these aspects have been proposed by de Haas (appendixC). de Haas (1996) suggests that the new tariff will be carried out every six months and will be based on a minimum of four samples taken during the preceding six month period to represent the quality of trade effluent discharged by a particular industry. The current tariff is being assessed by the City Council and the manner in which the new tariff is phased in will need to be decided by the Council.

The calculation of a new more equitable tariff is based on the option that the disposal of sludge will be carried via composting which has proven success and because of the comparatively reduced capital outlay. The costs of sludge disposal are included in determining the new tariff.

There are six components in the proposed tariff:

- C = Conveyancing and fixed costs at Darvill WWW
- COD = Treatment tariff based on organic load to Darvill
- OIL = Penalty for high concentration of oil and grease
- P = Penalty for high concentrations of phosphate
- M = Penalty for high concentrations of metals
- pH = Penalty for low or high pH

The overall structure of the trade effluent tariff would be:

Including conveyancing:

Cost (C/kl) = 158 + 0.28 (Ave. COD - 400) + Penalties (in Rands per month for specified months) for OIL + P + M + pH

Excluding conveyancing:

Cost (c/kl) = 90 + 0.28(Ave. COD - 400) + Penalties (in Rands per month for specified months)for OIL + P + M + pH

where: flow is in kl, COD is in mg/l, Penalties are calculated as described in appendix C.

This tariff is based on actual costs of treating wastes at Darvill WWW. The factor of 0.28 is calculated according to these actual costs and the percentage of industrial effluent relative to total influent. Differences are noted between the tariff including conveyancing and excluding conveyancing. Conveyancing charges are calculated on sewerage rates and for use of the sewers. COD has replaced OA as COD is viewed as a better measure of oxygen demand particularly at a plant like Darvill WWW. COD of 400mg/l is the base line for calculation of the calculation of the tariff, this level will account for normal sewage.

An alternative industrial effluent tariff can be derived according to the following formula which is used in Sweden (Opschoor and Turner, 1994):

$$T = F + V [s_2 + dv + K(O_i/O_f \cdot db + S_i/S_f \cdot df) + da]$$

where F = fixed cost depending on the characteristics of the source itself and of the area (total equivalent population and water endowment);

V = quantity (m^3) of the effluent discharged;

s_2 = average cost coefficient for the sewage service;

dv = average cost coefficient and preliminary and primary purification treatment;

K = parameter measuring the relative costs due to the characteristics of the single source (if the effluents discharged respect the quality standards for the treatment plant, $K = 0$);

O_i = COD of the industrial effluent;

O_f = COD of the overall effluents;

db = average cost coefficient for secondary purification treatment;

S_i = suspended particles content of the effluent;

S_f = suspended particles content of the overall effluent;

df = average cost coefficient for treatment and disposal of primary sludges;

$da = [M \cdot (db + df)]/100$, where M is the percentage increase in costs due to the different pollutant costs considered in the parameter's db and df .

The cost coefficients are determined as standards according to the total equivalent population and the endowment of the area. The charges are explicitly intended to finance the public sewerage and purification services. However, the structure of the charge may have incentive effects, both on the decision where to pollute and on the decision to pollute or to treat.

In particular, there is an incentive to treat pollutants differently from suspended particles and reducing agents and to discharge into public sewers pollutants containing suspended particles and reducing agents at a rate equal or lower than that of other sources.

However the current level of the charges are generally low. Economic instruments designed primarily to promote a reduction in pollution and not only to finance services as sewerage and purification, play a negligible role (Opschoor and Turner, 1994). Further research on the feasibility of such a tariff structure is required.

3.3.2.3 DRAINAGE BY-LAWS

PROPOSED AMENDMENTS TO CURRENT BY-LAWS

Current Industrial Effluent By-laws are being amended and are still under revision. Some of the changes that have been noted include;

Section 2 (1) states that *no person shall discharge or cause or permit to be discharged, any industrial effluent onto any land surface or into a natural drainage line or into any waterway or stream;*

Section 7 (1) (b) states that *industrial effluent will receive preliminary treatment before discharge into the sewer as is the opinion of the City Engineer..... and will render it innocuous to the plant and equipment of the treatment works;*

Section 7 has been amended to include conditions pertaining to correct sampling procedures for industrial effluent;

Section 8 (1) (c) allows the City Engineer to withdraw any permission to discharge to the sewers if the industry does not adhere to conditions as stated in section 7(1);

Section 8 (3) compels *the owner or occupier of the premises where permission to discharge has been withdrawn to take necessary steps to facilitate the disposal of industrial effluent by other means;*

Section 12 refers to the City Engineers authority to *refuse to grant permission to discharge to the sewers if certain conditions are not met.*

New draft drainage By-laws have been proposed but further amendments are required to determine a more effective local system of command and control. Problems with the implementation of amended By-laws have not been completely addressed by the revised By-laws.

3.3.3 UMGENI WATER

The agreement between the City Council and UW does not explicitly explain the responsibilities of the relevant controlling bodies. Umgeni Water should consider amending the agreement that it has with the City Council as they lack the authority to effectively control the situation while the Council lacks manpower. However, UW does possess the necessary equipment and apparatus for regular monitoring and it also seems possible that they could supply the necessary manpower. As agents of DWAF, UW recently held stakeouts which resulted in prosecution samples from the vegetable oil industries being taken. Communication problems between both organisations need to be addressed for better understanding between the organisations responsible for the discharge standards, monitoring and control of effluent. A workshop that will highlight these aspects involving at least the Council, UW, DWAF and the relevant industries is recommended.

Umgeni Water does not refuse to treat industrial effluent as this may encourage illegal dumping into rivers and streams and this will result in the environment being damaged. Although DWAF is responsible for external monitoring, an external auditor responsible for monitoring on a larger scale is needed. Since UW is in the best position to be responsible for catchment management. This should be carried out together with the external auditor. Discharges from Darvill WWW needs to be more closely audited internally and externally to ensure that pollution problems receive immediate attention.

3.3.4 THE RATEPAYERS OF PIETERMARITZBURG

If the ratepayers are made more aware of the current situation, public pressure could be used to find a sustainable solution. If industries were charged a more equitable fee for their portion of the pollution load, then the contribution from industries to the overall costs of operating Darvill WWW could increase three-fold. The burden of costs to domestic users/ other ratepayers would then drop. This amounts to R280 000 per month and is equivalent to R17million over five years in today's rands.

3.3.5 DOWNSTREAM USERS AND AFFECTED RESIDENTS

Downstream users include informal communities situated along the Msunduzi river, Pietermaritzburg residents, downstream ecology and communities relying on Inanda dam as a source of treated water. Negative impacts to downstream users can be used to highlight the problems caused by poor regulation. Governmental organisations such as DWAF and the Department of Health will be directly affected by these issues pertaining to economic, health and the overall quality of life of affected parties. The possible deterioration in water quality of Inanda Dam and escalating treatment costs to UW also need to be investigated.

3.3.6 DEPARTMENT OF WATER AFFAIRS

Industries and individuals should be made responsible for cleaning up pollution that they generate and they should ensure that their activities do not interfere with the natural state of the environment, but this is not always possible. This can be done by promoting laws and regulations and by introducing economic incentives. Since DWAF is the national controlling body, it is in the best position to promote such regulatory mechanisms.

Ideally, a hybrid control instrument should be developed to suit local conditions. However, this may not be practical without national policies and standards or sufficient resources to ensure effective monitoring and control. Sustainable water management requires reusing water, charging polluting industries for clean up costs and improving and enforcing government regulations. Governments must also create more awareness in water use but it is becoming increasingly difficult as development and industrialisation gathers momentum. National policies for effluent tariffs are needed so that industries are persuaded to conform to certain minimum requirements. National legislation could discourage industries from moving to new locations to avoid higher tariffs, as City Councils would also no longer be able to offer lower tariffs to attract industries. Restructuring of the industrial effluent tariff formula would need to be accompanied by effective and efficient monitoring and control by the relevant water authorities. This would have cost implications for local authorities who may have higher priorities in terms of competing development needs.

3.3.6.1 DWAF MANAGEMENT POLICIES AND STRATEGIES

Two pillars of DWAF's recent approach to water quality management were a Receiving Water Quality Objectives (RWQO) approach and the Precautionary Principle (DWAF, 1991). Receiving Water Quality Objectives focus on the fundamental water quality management goal, namely fitness for use, while the Precautionary Principle encompasses all types of action to avert danger and minimise risk to the environment that may result from limitations of the RWQO's. The option of incentive-based pollution regulation strategies to supplement command and control have also been investigated. This aims to encourage the "polluter pays" principle and has listed sequential steps for the design of a monitoring system.

The "polluter pays" principle requires dischargers of effluent to meet the cost of treating their effluents adequately and of repairing the consequences of damage to the environment from their discharges (DWAF, 1994). Until the policy is fully operational, the current General and Special Effluent Standards serve provisionally as minimum effluent standards. Adaptation of the General and Special Effluent Standards to comply with proposed minimum or industry related standards is urgently needed. Further investigations need to determine whether current standards are fair. The DWAF is currently reviewing these issues.

The RWQO require the determination of water quality objectives for desirable water uses, understanding the relationship between pollutant loads and water quality. These are used to predict the impacts on the water environment as well as the economic impacts and socio-political constraints. RWQO have been used where polluters have approached DWAF for a relaxation of the General or Special Standards. The Special standard is only used in special circumstances and is usually intended to set the required standard. If it does nothing else, the RWQO at least facilitates decision-making. Although RWQO have been criticized for not referring to a minimum level of effluent treatment, these minimum effluent standards are implied in the General and Special Effluent Standards, which are relaxed only when justified on the basis of RWQO or technological or economic grounds (DWAF, 1994).

Enforcement appears to be a major problem as the legal structure fails to make adequate recommendations for enforcement of policies. The command and control approach is used by DWAF to meet its responsibilities of managing water quality and controlling water pollution. The approach involves specification of environmental and/or emission standards, often also the waste treatment technology to be used and the behaviour of waste producers. The control authority is then responsible for instituting and maintaining elaborate legal and administrative systems to ensure compliance. The Water Act has vested seemingly adequate powers in the State to control industrial use of water and to control or prevent pollution from both point and non point sources. Requirements concerning certain actions are laid down in Sections 12, 12A, 12B, 21, 22, 23, 23A, 24 and 26 of the Act (DWAF, 1991). The current Act is under revision and some aspects pertaining to illegal discharge to surface waters may be amended.

Public participation in decision and policy making and the operation and implementation of such decisions and policies are encouraged by DWAF. Public participation has become the overriding reality as an important tool to overall environmental management. The issue of prosecution of offenders needs to be reviewed. According to the Water Act, the maximum penalty for a first offender is R50 000 and/or one year imprisonment, for second offenders it is R100 000 and/or one year imprisonment.

Section 171 allows the court the right to impose an additional penalty equal to the benefit gained by the offender through not complying with the Act or the Regulations. Violations of the Water Act are at present prosecuted as criminal offences only. The Act also specifies maximum fines. No provision exists for civil action in which, for example, damages might be claimed from someone who has caused damage by polluting the natural water body. The Water Act therefore has a number of limitations which need to be investigated (DWAF, 1991).

An additional problem is finding a proper linkage of water resource management with the more comprehensive environmental management. Many organisations at various levels of Government need to be involved in the decision-making process. At present such a structure is lacking.

Monitoring is also a requirement in Environmental Impact Assessment, which in turn is an important component in the Integrated Environmental Management Procedure for the establishment of waste management facilities (DWAF, 1994). The Water Amendment Act 96, 1984 broadened water quality management to include industrial effluent and counteracting pollution but efforts to control pollution have not been successful.

3.4 PROMOTING THE “POLLUTER PAYS” PRINCIPLE

If the environment is considered to be a common resource or free good, it is likely to be over-exploited and polluted. This is illustrated by the vegetable oil industries in Pietermaritzburg who choose the cheapest options in dealing with their effluent even if this causes the treatment works to be overloaded and subsequently, rivers and dams to be polluted. The costs of negative impacts on the environment need to be taken into account and polluters should be made to pay for their activities. For the “polluter pays” principle to be successful, an effective and efficient legal and administrative structure is needed. Legislation needs to provide the means to more effectively implement the principle and administrative structures need to have the resources and power to effectively implement and enforce the legislation. In South Africa, it may be difficult to allocate the resources needed because of other competing and urgent development needs.

Because the production of goods and services uses environmental resources and treats them as if they were free, the price of goods and services produced do not reflect their true costs. The adjustment required is consistent with the principle of the polluter pays in which the polluter must pay for the cost of cleaning up the environment or the costs of the environmental damage done by producing the good in question. This can be done by imposing a charge on the good for its pollution content. In practice pollution costs are rare and the principle of the polluter pays is usually implemented by making the polluter pay the costs of regulations designed to achieve a given environmental standard (Pearce&Warford, 1993).

In Czechoslovakia water pollution fees are paid for the right to discharge wastewater to surface water and once the acceptable limit of pollution has been exceeded, the standard charge rises with the level of pollution. This could be an acceptable method of promoting the polluter pays principle but in Czechoslovakia the charge is insufficient because it is not high enough to induce industries to control pollution. Moreover, polluters are encouraged to discharge wastes to rivers because the charge for discharging to sewers is much higher than the charge for discharging to rivers. The reasons for this may be that the industries in Czechoslovakia may be involved in adequate on-site treatment which meets required standards for discharge to the rivers, therefore discharging to the sewers and being charged according to volume may not be the best option. It seems unlikely that such a situation may be possible in Pietermaritzburg as industries do not even make an attempt to discharge effluent that meets sewer discharge standards. They are not responsible enough to be allowed to discharge treated effluent to rivers.

3.5 ECONOMIC INCENTIVES AND INSTRUMENTS

The economic approach to environmental policy has now been generally accepted in most industrialised countries. It stresses the advantages of economic instruments which seek to modify human behaviour through a price mechanism. National legislation and local regulatory mechanisms need to investigate the use of various economic instruments which are available. Some of these instruments will work better than others when placed in the context of the current situation, however more research is required to determine the most appropriate economic instrument. Ecotaxes can be viewed as one of the initiatives to encourage better environmental practices. A variety of approaches include emission, product and user charges, marketable permits, deposit refund systems and subsidies. Refundable taxes encourage the cleaning of industry while other revenue-neutral measures such as refund deposit systems have proven effective. Sales taxes can be used to impose a higher level of taxation on environmentally unfriendly products and technologies (Keeping Track, 1996). Ecotaxes cannot substitute completely for regulations. Environmental protection and preservation will more likely be achieved if the two are used together.

A hybrid system of economic incentives may be the most effective means of dealing with the problem of pollution (Baumol and Oates, 1992). A hybrid system is one of marketable permits with a pollution charge (an effluent fee) and a subsidy all in one. The government issues marketable emissions permits and the permits are traded until an equilibrium price is established. In addition, firms are allowed to generate pollution over and above the level specified in their permits but they must pay an effluent fee per unit for the privilege. The government could also offer a subsidy, per unit, for any unused permits (Baumol and Oates, 1992).

In equilibrium the subsidy must be less than or equal to the price of the emission permits which in turn will be less than or equal to the effluent fee. This relationship is explained by the fact that if emission permits were more expensive, per unit, than the effluent fee, then firms would simply pay the tax rather than buy the permits and so the price of the permits would have to fall. In the same vein, if the subsidy per unit was greater than the price of the permits it would pay firms to buy permits, not use them, and profit from the difference between the subsidy and the price of the permit. For this reason nobody would be willing to sell permits at a price lower than the subsidy (Pearce & Warford, 1993).

An advantage of a hybrid system such as this is that, to some extent, it corrects errors that can occur when the controlling body (Council or UW as is this case) does not correctly estimate the optimum level of pollution (Tietenberg, 1992). If the optimum level of pollution level is underestimated then it will be attempting to force a level of emissions reductions that is greater than the social optimum. In this situation the cost to firms of reducing their emissions will be greater than the effluent fee and so they will emit more than is specified on their permits and pay the tax. In this way the loss to society will be reduced if detected. In the same way, by overestimating the optimum level of reductions, clean-up costs will fall below the level of the subsidy. In this case polluters will not use all of their permits but receive the subsidy instead, reducing emissions to a level closer to the real optimum (Baumol and Oates, 1992).

Implementing the hybrid system would present a number of problems. Firstly, a hybrid system such as this requires some idea of the optimum level of pollution, although the hybrid system will correct errors in this estimate to some extent. The DWAF and UW will need to work together in order to develop optimum pollution levels specific to the river system, further investigation is needed to determine whether individual rivers will be given specific optimum levels of pollution or whether standards such as DWAF's Water quality standards with general and specific standards will be used.

Secondly, a system of marketable emission permits will only work if the costs of trading permits are low. Also, for such a system to work, a very accurate monitoring system is required in order to establish exactly which companies are exceeding their permits, and by how much, and also which companies qualify for subsidies, and the extent of those subsidies. Umgeni Water and the City Council need to determine who will be responsible for monitoring and the authority that will be given to the monitoring body. The existing situation is clearly ineffective so UW either needs to be given more authority for making decisions pertaining to monitoring or the Council needs to take on this responsibility.

3.5.1 MARKETABLE PERMITS

Tradeable or marketable permits are market-based instruments (MBI) that regulate environmental pollution. The MBI approach regards traditional forms of regulation, based on command and control, as unnecessarily bureaucratic and inefficient. The first step is to determine an acceptable level of pollution, then permits are issued for the level of allowable emissions, up to the allowable level. These permits are environmental quotas, allowances or ceilings on pollution levels (Turner *et al.*, 1994). Initial allocation of the permits is related to some ambient environmental target, but thereafter permits may be traded subject to a set of prescribed rules as shown in Table 19.

Under the tradable permits system the allowable overall level of pollution, based on assimilative capacity of the receiving environment including the capacity of the Works and cost issues, is established and allotted in the form of permits to individual polluters.

Polluters that keep emission levels below their allotted level may sell their surplus permits to other polluters or use them to offset excess emissions elsewhere on their premises. Low-cost controllers have an incentive to control to a greater degree than they need and high-cost controllers have the option of buying permits instead of undertaking costly control measures. The marginal costs of pollution control tend to equality for all polluters and hence the total cost of pollution control to society is minimized (DWAF, 1994). In economic terms, the optimal situation is reached where marginal costs are equalised through the trading of permits among polluters who face different costs of pollution control.

Marketable permits depend heavily on the market conditions in a particular industry if they are to generate efficiency gains. The competitive nature and the size of the market are critical factors. They are an innovative and challenging way of tackling water pollution because they leave the polluter with the flexibility as to how to adjust the environmental standard. They do not sacrifice environmental quality because the overall level of quality is determined by the overall number of permits and this is set by the regulatory authority (Turner *et al.*, 1994).

The first step to introducing marketable permits in Pietermaritzburg is identifying an acceptable level of pollution. Together UW and DWAF can determine an acceptable level of pollution. Since UW is actively engaged in both catchment management and environmental auditing in the area they will be able to assist DWAF in setting acceptable levels of optimal pollution. It is important to maintain a holistic perspective when deciding on the acceptable level. Some issues that should be considered include, effects to all communities (social and ecological), long-term effects (pollution build up), realistic levels and the people who will buy and trade these permits. Since permit trading depends heavily on market conditions, the market in Pietermaritzburg needs to be carefully analysed. The vegetable oil industries could monopolise the market. The size and competitive nature of the market are critical factors; a big enough market will allow competition while still achieving low administrative cost-effectiveness. Environmental effectiveness may be a problem if regulatory constraints on permit-trading are required in order to control potential localised areas of extreme pollution. If the vegetable oil industries create such areas marketable permits will not be effective.

Acceptability among industrial interests will be low unless long-term contractual arrangements or brokering facilities can be arranged. Due to the past lack of co-operation from the vegetable oil industries, it is not likely that marketable permits will work without strict control or contractual arrangements. If this economic instrument is decided upon it will be necessary to engage a controlling body. Thus, far responsibility has been shifted from one organisation to another, so it is suggested that a single independent body be formed with the main aim being monitoring and regulation of pollution.

TABLE 19 Characteristics of Marketable Permits

BASIC AIMS AND ADVANTAGE	BEST PRACTICE CONDITIONS	ENVIRONMENTAL MEDIA RELEVANCE	LIMITATIONS
* Savings in compliance cost	* Differences in marginal compliance costs	* Water-low	* Limited applicability to more than one pollutant simultaneously
* Can encompass effect of economic growth	* Maximum ambient pollutant concentrations are fixed	* Air-high	* Pollution hot spots may be exacerbated
* Flexibility	* Number of polluters large enough for market to form and operate	* Waste-low	* Initial allocation of permits requires careful consideration
* International pollution abatement	* Better applied to fixed pollution sources	* Noise-low	* Administrative complexity
	* Potential for technical innovation		* High transactions costs if there are many polluters
			* Low levels of banking and trading of permits.

(Source: Turner *et al.*, 1994)

3.5.2 POLLUTION CHARGES

These systems impose a fee or tax on the pollution load which is similar to the current Council system. Consequently, it pays to reduce pollution to the point where the marginal cost of pollution is equal to the pollution tax rate. Different polluters end up controlling different amounts of pollution. Examples of water pollution charges are found in several western European countries. A disadvantage of the pollution charge system is that the authorities imposing it do not know in advance what level of environmental protection will result from a given charge (DWAF, 1994).

Pollution charges include emission charges, user charges and product charges (Turner *et al.*, 1994). Emission charges are charged on the discharge of pollutants into air, water or soil. They are related to the quantity and the quality of pollutant and the damage costs inflicted on the environment. User charges have a revenue-raising function and are related to treatment cost, collection, and disposal cost, or the recovery of administrative costs depending on the situation in which they are applied. They are not directly related to damage costs in the environment. Product charges are levied on products that are harmful to the environment when used in production processes, or when consumed or disposed of. The charge rate is related to the relevant environmental damage costs linked to the target product (Table 20).

Pollution charges should also induce more recycling as disposal becomes more expensive. A system that perfectly charges consumers all of the social costs of disposal of each item of refuse would require comprehensive monitoring and enforcement and would therefore carry prohibitively high transactions costs (operating and administration). Real world systems must balance the efficiency gains of a perfect pricing system and the transaction costs of such a system in place. Disposal charges based on volume or weight of waste score reasonably well on the environmental effectiveness and economic efficiency criteria. Some communities seem to be able to operate such simple systems without the prohibitive transactions cost penalties (Opschoor and Turner, 1994).

Pollution taxes provide an important route for internalising the external pollution damage costs caused by companies and restricting their pollution emissions to a sustainable optimal level. They also send signals to consumers regarding the pollution consequences of their purchases. Further more, the regressive impacts of these taxes on the poorer sections of society can be adequately compensated for by a system of tax redistribution (Turner *et al.*, 1994).

Pollution charges are similar to the industrial effluent tariff used in the City. Like the tariff the disadvantage of pollution charges is that there is no prior knowledge of environmental protection for a given charge. However an important component that is lacking in the current tariff is that the charge rate needs to be related to the costs of relevant environmental damage. A new tariff should take relevant environmental damage into account. Tariffs proposed thus far are based mainly on operating costs and COD concentrations.

TABLE 20 Characteristics of Pollution Charges

BASIC AIMS AND ADVANTAGE	BEST PRACTICE CONDITIONS	ENVIRONMENTAL MEDIA RELEVANCE	LIMITATIONS
* Savings in Compliance Costs	* Stationary point-pollution	* Water-good prospects eg France, Germany and Netherlands	*Limit on number of pollutants that can be covered
* Dynamic incentive effect	*Variable marginal abatement costs between Polluters	*Air -medium monitoring eg Sweden	*Distribution effects
* Revenue raising potential	*Monitoring of emissions is practicable	* Waste-low	*When revenue raised is earmarked, a coherent allocation system is required
*Flexible system	*Potential for polluters to reduce emission and change behaviour		
	* Potential for technical innovation		

(Source: Turner *et al.*, 1994)

Pollution charges should induce more recycling as disposal becomes more expensive. If this should be encouraged in the City, some industrial effluent problems at Darvill WWW will cease. Pollution charges should be based on volume, weight or composition of effluent like the tariff proposed by de Haas (1996) which is based on COD (a measure of oxygen load) but damage to the environment should also be considered. The accurate determination of an appropriate pollution tax level depends on accurate information regarding the damage costs of that pollution and the benefits of its associated production of goods (Turner *et al.*, 1994). Intensive research and investigation are required for the implementation of such a tariff. If pollution charges are recognised as a workable instrument, it is necessary that an efficient regulatory body be formed.

3.6 CONCLUSION

Darvill WWW, the wastewater treatment plant serving the greater Pietermaritzburg Area, has been experiencing problems due to the deteriorating quality of industrial effluent. Effluent containing large concentrations of SOG is the major cause of problems. The vegetable oil industries are predominantly responsible for these problems. Due to an ineffective regulation mechanism it is difficult to find a workable solution to these problems. To establish an effective management plan, it is imperative that the current situation be addressed holistically. A forum of interested and affected parties needs to be established immediately to assess the involvement and willingness of the affected parties. This will promote the establishment of a workable solution to the problems being generated by the vegetable oil industries. Affected parties include the vegetable oil industries, UW, the Pietermaritzburg City Council, and DWAF. National and local legislation needs to be reviewed but it has been established that changes are being considered on both a national and a local level.

Local command and control mechanisms include the industrial effluent tariff and drainage By-laws. Both structures are under revision, the current tariff has been updated and will be enforced from 1997.

However this tariff is still viewed as being inequitable. Some alternative structures have been proposed, based on the operating costs of Darvill W^WW with respect to the volume and composition of industrial effluent. Conveyancing costs and sewerage rates are also included. Current By-laws are also being revised to give the Council more control. The revised By-laws have not clarified sampling and monitoring issues.

A City disposal site for industrial effluent needs to be investigated as the existing site is not suitable but it may be upgraded. Self-regulatory measures have also been investigated. The vegetable oil industries can reduce pollution if cleaner technologies are used. On-site treatment can reduce high concentrations of SOG which are causing problems at the Works. These include the physical-chemical, solvent extraction and concentration, evaporation and distillation methods. Existing on-site treatment facilities are limited. There are some costs involved in setting up new on-site treatment plants but costs vary according to the needs of the industries. Industries can also benefit from primary treatment since recycling is possible. These methods will not solve the problems in the long term unless the industries change their attitudes towards waste management, employ well-trained staff and technicians for the operation of the systems proposed, set up a budget to run the system and maintain the system. These issues should be regarded as part of the industrial process and should be included in the industries financial plan. Economic instruments including pollution charges (taxes) and marketable permits have been reviewed. These instruments create incentives for pollution abatement instead of forced regulation and control. Thus, far regulation of industrial effluent disposal has been through monitoring and control. Due to the past lack of co-operation from the vegetable oil industries further investigation into the use of economic incentives is required. The hybrid system of self-regulation may provide a possible solution.

National water pollution command and control policies indicate that very little attention is given to pollution of the sewers. Local Councils have greater control of sewers and waste water treatment than DWAF which is responsible for water quality standards. These standards apply to treated water being discharged to surface water and rivers. Regulation of activities that directly affect the source of freshwater is emphasised and pollution is recognised as a problem when wastes are dumped into rivers, public water systems and vacant land.

However DWAF is in the process of adopting alternate policies. Receiving Water Quality Objectives are in the process of being implemented. Those issues that are not covered by RWQO are addressed by the Precautionary principle. Further investigation is required into effective means of applying the law. Irrespective of the system that is adopted it is important that an effective method of implementing a deterrent be adopted.

The “polluter pays” principle is rapidly gathering acceptance and it would help solve the local pollution problem if it is more effectively implemented. DWAF supports the ideas of the “polluter pay”’s. The City of Pietermaritzburg would definitely benefit if this principle is more effectively adopted since ratepayers are currently subsidising polluting industries. The current situation needs immediate revision and the issues raised in this Chapter provides a framework to achieving a sustainable working solution.

CONCLUSION

It is important to define both the environment and development as the interaction of physical, cultural, economic and biological factors which routinely influence the lives of individuals and communities of present and future generations. Equally, it is necessary to develop a comprehensive set of indicators which will provide a holistic assessment to plan and implement effective and beneficial policies for sustainable development and the conservation of the environment. Resource management can only be achieved if resource use is properly measured and analysed with the assistance of effective indicators.

The development and communication of such indicators represents an interdisciplinary challenge that requires talents from diverse disciplines and viewpoints. With the development of adequate indicators, objectivity will replace subjectivity. Responsible decision-making in government and other institutions depends on the availability of reliable information. If effective management of the environment and valuable resources is to be achieved comprehensive data about the status and changes of the environment must be developed.

The Sustainable Development Records (SDR) method is currently being tested in a number of Swedish companies and municipalities. Experience has shown that this performance language functions as an alarm clock, general information carrier and a springboard for new thoughts and technical innovations. A great advantage of SDR is that it improves the communication on environmental issues between various groups in society. The SDR highlights different aspects that politicians, technical staff and environmentalists can focus on. It is based on measuring Effectiveness, Thrift and Margin(key indicators). Trends or patterns in resource use become more easily understood if there are some common and simple rules controlling the way indicators are constructed. A useful management tool can be made from a careful set of SDR key indicators recurrently measured and reported over time.

The SDR was used in this study as a management tool for Darvill Waste Water Works and problems with the vegetable oil industries became apparent. Study results are intended to get interest groups in Pietermaritzburg to think in economic terms. A lack of communication about the effects of effluent disposal from the vegetable oil industries in Pietermaritzburg is causing major disturbances to the Works.

The SDR analysis of Darvill WWW proves the importance of and the need for, adequate development indicators. Wastewater treatment is an important function since water is a vital natural resource and the supply of fresh water is being rapidly reduced due to increasing demands from expanding populations and industrialisation. Wastewater treatment allows water to be recycled and returned to a source of freshwater. It also reduces pollution through the effective treatment of water borne sewage.

Indicators are important in this process as treated water not only impacts on human beings but also on river ecosystems and natural biota. The performance of the overall water treatment process at Darvill WWW is assessed to determine whether the services provided are sufficient and adequate. This was carried out using key indicators, Effectiveness, Thrift and Margin from the SDR model for the period 1993-1996.

Effectiveness was measured in terms of compliance of selected water quality variables with the standard. Thrift was measured in terms of the capital, labour, energy and chemical thrift. Margin was assessed by the difference between non-complying samples and the standard. These indicators provided information for decision makers and management of Darvill WWW. Targets and goals are established to determine acceptable limits of pollution, indicators are measured regularly in order to determine whether these targets are being met.

Effectiveness of Darvill WWW operations seem to be acceptable for most variables. Problems have been identified with *E. coli* and Ammonia. Compliance of Chlorine and Chemical Oxygen Demand has improved significantly. Deteriorating compliance has been linked to the poor quality of industrial effluent. Incoming industrial effluent containing large concentrations of soap, oil and grease (SOG) are responsible for major disturbances to the Works. The vegetable oil industries have been identified as the industries responsible for high levels of SOG. Improved compliance is attributed to improved plant efficiency due to renovations and extensions. The plant has become thriftier in terms of chemicals used but financial thrift, energy thrift and labour thrift has decreased. Renovations and extensions have increased the capital demands of the plant thereby reducing financial thrift. These renovations are also responsible for the decrease in energy thrift as the new equipment has a higher energy demand. Labour thrift appears to have increased because the plant is increasing the use casual labour (the number of casual labourers almost doubled during the study). Chemical thrift has decreased since less chemicals are needed for biological phosphate removal. Darvill WWW chooses biological phosphate removal as the wastewater treatment process. Margin differences fluctuate but *E. coli* seem to be a cause for concern. Increased margin is linked to the deteriorating quality of industrial effluent.

Although Darvill WWW is achieving compliance with water quality standards, the costs of effectively treating wastewater seem to be increasing as indicated by the decreasing thrift. The SDR analysis indicates that the vegetable oil industries are partly responsible for increasing cost due to their discharge of effluent containing high concentrations of SOG.

Darvill WWW as a social institution is thus performing effectively, but at an increasing cost, possibly because local ratepayers are subsidising local industrial polluters due to a tariff structure which does not reflect the full costs of pollution. When Darvill WWW is unable to fully treat industrial effluent from the vegetable oil industries, pollution of downstream rivers and dams increases. Both social and ecological communities are affected as treated water is discharged into the Msunduzi river. Evidence indicates that a this river impacts on social and natural environments. These industries need to be made aware of the environmental, economic and social costs of ineffective effluent disposal and encouraged to process their waste to a specified standard prior to discharging to the public sewers. Public pressure through informing the public could assist in control but regulation through command and control is currently employed. The current industrial effluent tariff and drainage By-laws are under review, which could help to reduce future water pollution levels.

Legislation and more effective implementation and regulations may be developed. However self- regulation through economic incentives such as marketable permits and pollution chargers is another avenue that needs to be considered. It seems unlikely that the situation with the vegetable oil industries will be regulated through self- regulation alone. A hybrid system of self-regulation may be a better alternative for the Pietermaritzburg case.

Optimal pollution levels need to be determined if economic incentives are to be used. This will not be easy but UW and DWAF could help set target pollution levels. A major problem is a lack of communication so a forum to promote active participation of all interested and affected parties should be established. Issues that need to be addressed include the responsibility and authority of UW, the Council, DWAF and the vegetable oil industries. Monitoring and control duties need to be clarified.

National legislation needs to be amended to make it less difficult for the prosecution of offenders. The Water Act is currently under revision. Local legislation is being redrafted to take more action against illegal behaviour. Greater consideration needs to be given to issues pertaining to discharge standards, control and monitoring, the collection of samples, the cost of treatment and waste disposal and the establishment of a disposal site.

The current industrial effluent tariff in Pietermaritzburg is outdated and it needs to be further revised. Although the tariff has been updated recently, it is still not equitable as ratepayers continue to subsidise the vegetable oil industries. Suggestions have been made for a new and more equitable tariff. The City Council's amended tariff for the next assessment indicates that changes are being considered but more work needs to be done to develop a more equitable tariff. The principle of the "polluter pays" needs to be more strictly enforced. Local industries need to be made more aware of their actions and they should take responsibility for the operation of their plants. Industries that practice clean technology and promote clean practice will be better able to achieve acceptable standards of plant operation. Effective industrial effluent disposal is an important part of this. Local industries should be introduced to cleaner practices and they should be forced to adopt more environmentally sound methods of production.

Areas for future research with regard to discharging treated water include, a detailed study to assess the impacts of discharging treated water with high *E. coli* concentrations and the ecological impacts on the Msunduzi river due to the discharge of treated water. Detailed analysis is also required on the full impact of high levels of SOG. Regulation with respect to the disposal of wet trade effluent in Pietermaritzburg requires review to include more effective By-laws and a more equitable tariff. The use of economic instruments as incentives also needs to be investigated to determine whether marketable permits and pollution charges will work in Pietermaritzburg. Legislation and the powers of DWAF also need greater attention. An effective way of implementing adequate deterrents needs to be investigated.

The SDR study indicated that Darvill WWW seems to be effectively treating wastewater but the cost/benefit analysis indicates that the costs of doing so are increasing. Effluent mainly from the vegetable oil industries seem to be causing problems. An investigation into the management of wet industrial effluent in Pietermaritzburg highlights the fact that changes need to be considered on a local and a national scale. The implications of solutions proposed will result in solving the problems caused by the vegetable oil industries. Umgeni Water will benefit from reduced costs to Darvill WWW. The operating capacity of the Works will also improve if the industries attempt to regulate pollution through clean technology.

Damage to the environment will decrease. Downstream users will also benefit from improved conditions. If the principle of the polluter pays is enforced the ratepayers will no longer subsidise waste water treatment costs. Economic instruments will encourage self-regulation. Industries will be given the option to monitor and control the level and composition of industrial effluent that is discharged. The City Council and DWAF will benefit from more co-operation with the vegetable oil industries.

SUMMARY

The development of effective socio-ecological indicators provide useful management information for sustainable development plans and for preserving the environment. Sustainable environment indicators require a more holistic overview that includes economic as well as ecological variables. The Sustainable Development Records (SDR) method used indicators to help environmental managers to assess the overall performance of any given social institution, such as a wastewater treatment plant. These indicators measure Effectiveness (ecological), Thrift (economic) and Margin (ecological) aspects of institutional performance. The SDR approach is applied in this study to assess the performance of Darvill Wastewater Works (WWW) during 1993-1996. According to the measure of Effectiveness, Darvill WWW is effectively achieving compliance with most national water quality standards. However *E. coli* levels indicate a substantial decrease in compliance during 1993-1996, while other water quality variables (Chemical Oxygen Demand, Ammonia, Soluble Reactive Phosphate, Chlorine, Total Suspended Solids) produce varying and fluctuating trends. Higher *E. coli* concentrations result in serious health risks to downstream users as both ecological and social communities are most affected by non-compliance. High concentrations of soap, oil and grease (SOG) from industrial effluent from the vegetable oil industries have been linked to non-compliance at the Works. No problems are noticed with the measure of conductivity.

Increasing demands placed on the Works as a result of deteriorating quality of incoming industrial effluent have made the plant less thrifty. The Works has become less thrifty with respect to finances, energy and labour while chemical thrift has increased. Increasing chemical thrift is attributed to increased reliance on biological phosphate removal and decreasing use of chemicals. Financial thrift has decreased as a result of additional capital which was needed for renovations and extensions. Improvements were needed at the plant to cope with the poor quality of industrial effluent. Labour thrift appears to have increased but increasing causal labour expenses indicate that this is not the case. Increasing demands being placed on the Works by the poor quality of industrial effluent. Energy thrift has decreased as a result of the new equipment to improve operational capacity of the Works.

The compliance range at the Works is within the standard range most of the time for most water quality variables. As with the measure of Effectiveness problems are also recognised with *E. coli* concentrations. Increased marginal difference is associated with industrial effluent of poor quality. Effluent containing high concentrations of SOG is a particular problem.

The Darvill WWW appears to be functioning in a socially responsible manner, but there is evidence of a disturbances. An investigation of the natural environment affected by the Works indicates that damage is being kept minimal to date. The overall conclusion is that Darvill WWW is being effectively operated but that the costs of achieving this high level of performance were increasing (reduced thrift).

Since high concentrations of SOG are causing problems to the Works, the reasons for this disturbance were investigated. This led to a suggested framework for a management plan for the disposal of wet trade effluent from the vegetable oil industries. The current system of regulation maintained through command and control via the City By-laws, trade effluent tariff and national laws is not effectively implemented in the Pietermaritzburg area.

Although the current system is being revised, the need for more change is highlighted. Greater participation is required from all interested and affected parties. The lack of communication amongst the stakeholders is a major problem. UW, Pietermaritzburg City Council, Department of Water Affairs and Forestry (DWAF) and the vegetable oil industries have been identified as the major stakeholders.

Alternative methods of self-regulation by the vegetable oil industries have been proposed, this includes the system of clean technology. Environmentally aware countries such as Canada and Sweden have successfully adopted cleaner practices in many industrial fields. Further investigation is required to determine whether the vegetable oil industries will consider cleaner technology as an option to trade effluent problems or if it will be necessary to force their co-operation. Methods of clean technology for these industries include the physical-chemical, solvent extraction and evaporation-distillation methods.

The minimum cost of setting up a primary treatment plant is between R100 000 and R500 000 and the average time period required is about three months. The City Council needs to consider options of disposal for wet industrial effluent. There is no longer a disposal site in the City. Further investigations are needed to assess whether it will be possible to establish a disposal site. If regulation through control is to be maintained, then monitoring and sampling techniques need to improve as the current system favours industries. An alternative method of regulation is the use of economic instruments as incentives. Subsidies, marketable permits and pollution charges could be considered as alternatives to command and control through policies and laws. Industries have been given incentives to reducing and controlling pollution successfully in many overseas countries. Further investigation is needed to determine whether it will work for the disposal of wet trade effluent in Pietermaritzburg. The current situation with the vegetable oil industries appears unlikely to be regulated successfully by such a system. The vegetable oil industries have been somewhat environmentally irresponsible, so it is uncertain whether they will willingly regulate pollution.

More enforcement of “polluter pays” principle also requires further investigation for reducing water pollution. The costs of treating industrial effluent are being incurred inequitably by the City ratepayers. A new industrial effluent tariff needs to be considered and has been suggested in this study. This tariff will take into account inflation and other adjustments such as penalties for illegal discharges of heavy metals and soap, oil and grease. The set of SDR indicators used in this study can be applied to improve communication between stakeholders concerned with water pollution in Pietermaritzburg. Trends or patterns can be recurrently measured and reported over time to assess whether Darvill WWT and other institutions develop in a sustainable direction. A major problem will be the need for UW and DWAF to establish acceptable pollution levels for the Msunduzi and other rivers.

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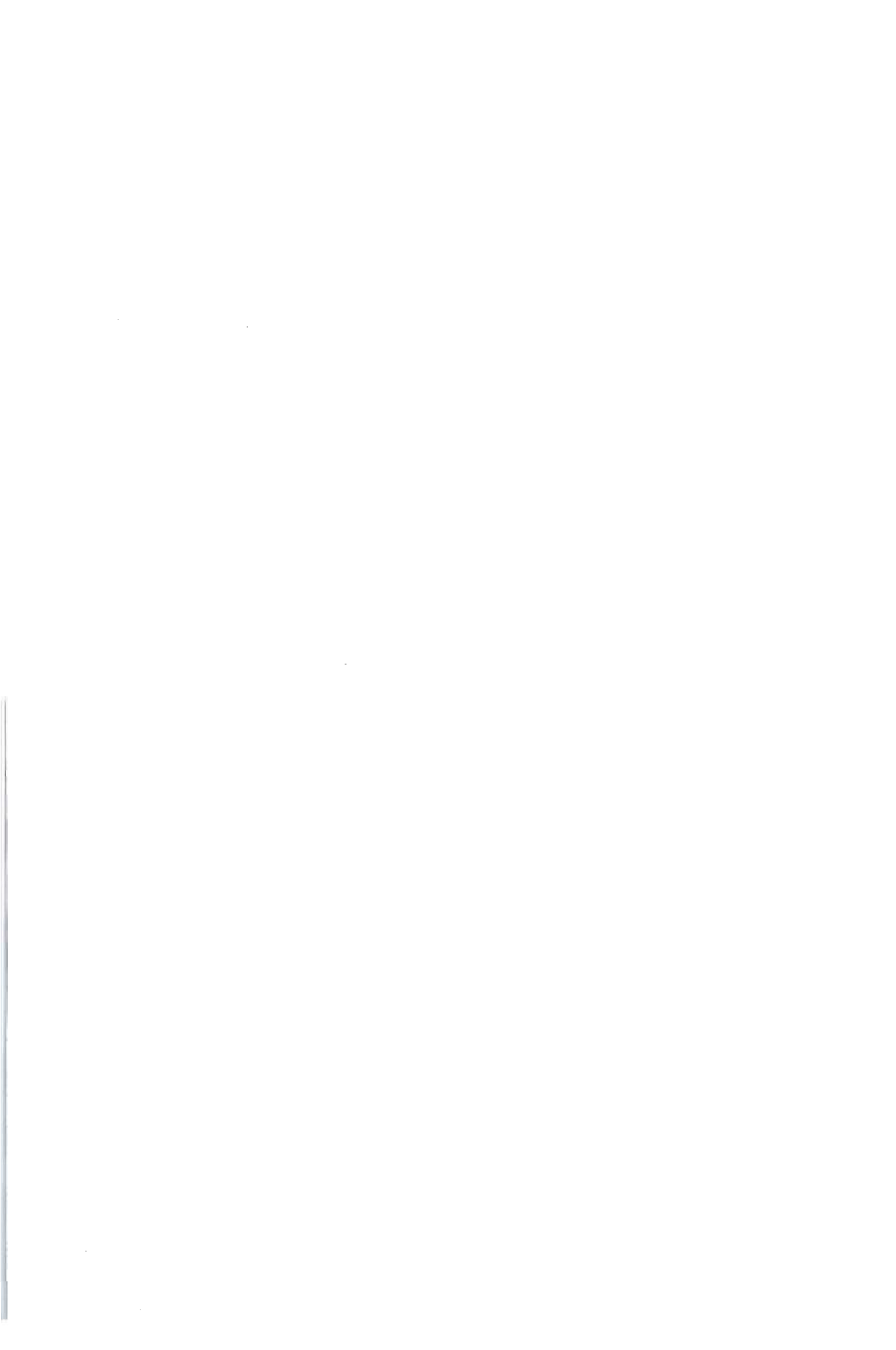
APPENDIX A 1 DWAF GENERAL AND SPECIFIC STANDARDS (1984)

WATER QUALITY VARIABLE	UNIT	GENERAL	SPECIFIC
AMMONIA	mg.l ⁻¹	10	1.0
ARSENIC	mg.l ⁻¹	0.5	0.1
BORON	mg.l ⁻¹	1.0	0.5
CADMIUM	mg.l ⁻¹	0.05	0.05
CHEMICAL OXYGEN DEMAND	mg.l ⁻¹	75	30
CHLORINE	mg.l ⁻¹	0.1	0
CHROMIUM HEXAVALENT	mg.l ⁻¹	0.05	no standard
CHROMIUM TOTAL	mg.l ⁻¹	0.5	0.05
COLOUR		nil	nil
CONDUCTIVITY	mS.m ⁻¹	75 above intake	15% above intake
COPPER	mg.l ⁻¹	1.0	0.02
CYANIDES	mg.l ⁻¹	0.5	0.5
DISSOLVED OXYGEN	% sat	75	75
FAECAL COLIFORMS	per 100 ml	0	0
FLUORIDE	mg.l ⁻¹	1.0	1.0
IRON	mg.l ⁻¹	no standard	0.3

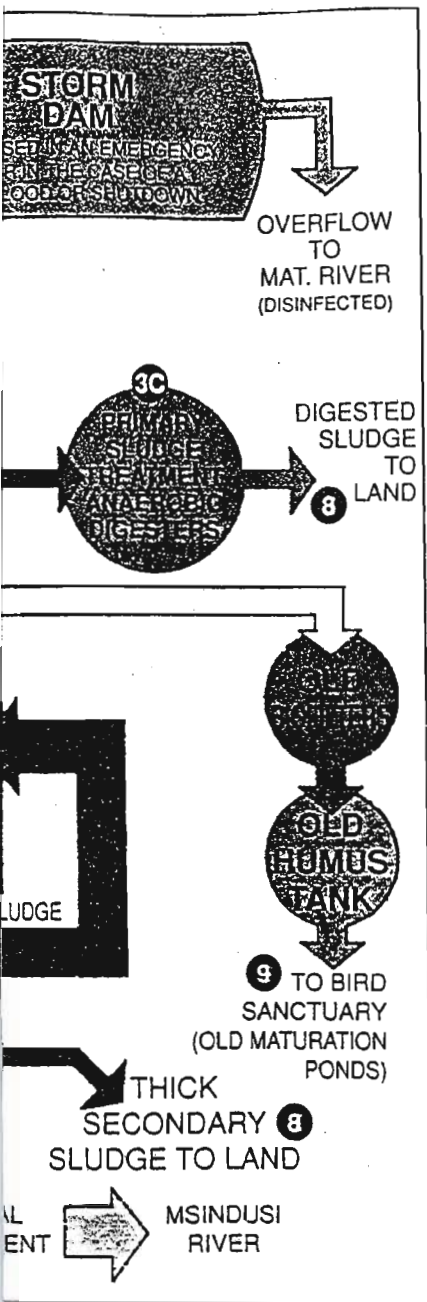
WATER QUALITY VARIABLE	UNIT	GENERAL	SPECIFIC
LEAD	mg.l ⁻¹	0.1	0.1
MANGANESE	mg.l ⁻¹	0.4	0.1
MERCURY	mg.l ⁻¹	0.02	0.02
NITRATES	mg.l ⁻¹	no standard	1.5
OXYGEN ABSORBED	mg.l ⁻¹	10	5
pH	pH units	5.5 - 9.5	5.5 - 7.5
PHENOLS	mg.l ⁻¹	0.1	0.01
PHOSPHATE	mg.l ⁻¹	no standard	1.0
SELENIUM	mg.l ⁻¹	0.05	0.05
SOAP, OIL OR GREASE	mg.l ⁻¹	2.5	0
SODIUM CONTENT	mg.l ⁻¹	90 above intake	50 above intake
SULPHIDES	mg.l ⁻¹	1.0	0.05
SUSPENDED SOLIDS	mg.l ⁻¹	25	10
TEMPERATURE	°C	35	25
ZINC	mg.l ⁻¹	5.0	0.3

APPENDIX A 2 Effluent Standards for respective catchments according to DWAF

EFFLUENT	CATCHMENT	STANDARD
Ixopo WWW	Mkomazi via Xobho river.	General
KwaMakutha WWW	Mbokodweni	General
Umlazi WWW	Sipingo	General
Mpumalanga WWW	Mlazi river upstream of its point of discharge into the sea.	General Special P
Hammersdale WWW	Mlazi river upstream of its point of discharge into the sea via <i>Sterkspruit</i> .	General Special P
Kwa Ndengezi WWW	Mlazi river upstream of its point of discharge into the sea.	General Special P
Mpophomeni WWW	Mgeni river upstream of the influence of tidal water via <i>Mthinzima stream</i> .	General Special P
Darvill WWW	Mgeni river upstream of the	General
Darvill WWW Old	influence of tidal water via Msunduzi.	Special P
Kwadabeka WWW	Mgeni river upstream of the influence of tidal water.	General Special P



WATER WORKS



removal of phosphate and nitrogen. In order to achieve this, the sewage passes through an anaerobic zone where it is deprived of oxygen and lime is added to control the pH of the effluent. Because activated sludge is living and grows, the growth is drawn off as waste-activated sludge. The remaining sludge is recycled and continues in the process for an average of about 12 days. The treated effluent passes through the process in about ten hours.

6A Secondary Settling Tanks (SST)

Treated effluent is separated from the activated sludge. In this process it is important for good settling to take place. Large pumps return the activated sludge from the bottom of the tanks to the activated sludge reactor described above. The treated effluent flows to the maturation river.

6B Dissolved Air Flotation (DAF) Plant

After passing through fine screens, waste-activated sludge is thickened by mixing it with water saturated with air produced under pressure. The activated sludge flocs attach themselves to the air bubbles causing them to float to the surface. At this stage the thickened sludge contains about one-tenth of the original water content. It is then scraped off the surface and pumped to the land for disposal with the primary sludge from the anaerobic digesters. The clear water produced from this plant (subnatant) is re-cycled into the activated sludge reactor. The sludge is pumped to the lands for disposal with the primary digested sludge.

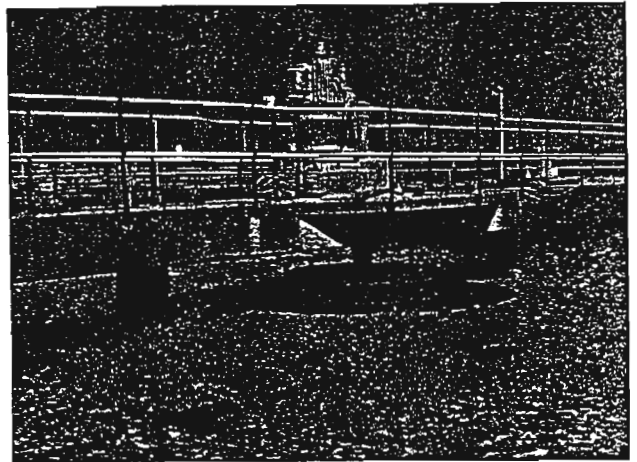
7 Maturation River

Treated effluent from the activated sludge plant is screened once more to catch remaining rags or pieces of plastic. Chlorine is added to the treated effluent to kill harmful human bacteria and viruses. Since chlorine takes time to act, the effluent passes through an artificial river called a maturation river for about 12

8 Sludge Disposal to Land

The thick secondary sludge from the DAF plant as well as anaerobically digested sludge is pumped to the land, where it is irrigated and ploughed in. Monitoring of land sludge for pollution takes place as a precautionary measure.

This land is not used immediately, due to protective laws imposed by the Department of Water Affairs and Forestry and the Department of Health to safeguard people from the spread of disease. Examples are the roundworm egg and other similar human disease-carrying



agents which take several months to die. Plans are in progress to dewater the sludge further before disposal to land. A crop may be planted on the land to help reduce possible run-off of water and nutrients which may pollute the river.

9 Bird Sanctuary Ponds

Partially treated effluent is pumped to the old maturation ponds through the biofilter and humus tank system in order to sustain bird life in the area. Any overflow from the fourth pond is recycled in the activated sludge plant.

Darvill Bird Sanctuary has, for many years, been regarded as one of the best inland water habitats in Natal and in 1988 it received national recognition from the Southern African Ornithological Society.

Darvill Bird Sanctuary is unusual as it contains not just a water habitat, but also woodland, plantation, grassland and scrub. As a result, a great variety of bird species occurs, with the total number of species recorded in the sanctuary exceeding 200.

al, the contents of the storm dam are pumped back to the works for treatment.

5 Activated Sludge Reactor

Large pumps take the settled sewage from the balancing tank at a maximum flow rate of 2 000 litres per second to the activated sludge reactor. Here a natural collection of micro-organisms which live in clumps (flocs) acts as a sweeping filter, removing many fine particles and organic pollutants. This produces clear effluent. Chemicals such as lime and alum can be added to aid flocculation.

APPENDIX C

REQUIREMENTS FOR A NEW INDUSTRIAL EFFLUENT TARIFF-AS PROPOSED BY DE HAAS

Any new tariff will need to take the following into account:

- *Rates - the question of sewerage rates and how they are levied should ideally be incorporated in the new tariff so that there is one charge based on one comprehensive formula for industrial effluent;*
- *Conveyancing - the cost of installing, maintaining and repairing the sewers (City Engineer's Dept.) will need to be included and should ideally be one component of the industrial effluent formula;*
- *Treatment costs - factors should be included not only for organic strength (preferably measured by COD instead of OA), but also for variables which have an important impact on the process at Darvill. Typically these would include phosphate, oil and grease and metals⁸. In a similar manner to the OA load cut-off (0.5% of total load) used to define the "high strength" industries in the above-mentioned argument for illustrative purposes, a threshold can be set for phosphate, oil and grease, metals and pH, below which no additional charge is levied in respect of industrial effluent. However, above these limits, a charge factor may be incurred, either proportional to the increased operating costs (where the phosphate can be removed, for example, by adding more chemicals in the primary treatment stage), or as a "penalty tariff" designed to discourage the discharge of these substances to sewer and*

⁸ Metals (both transition group metals and heavy metals) have an impact on the treatment process because they are largely removed at the Works and bind with the sludge fractions produced. The sludge in turn must be disposed of, and an elevated metal content in the sludge can preclude or limit certain agricultural uses of the treated sludge. Wastewater sludge (or preferably termed biosolids) treatment and disposal is a subject in itself. UW is currently engaged in a strategic assessment to determine the viability of various future sludge disposal options for Darvill Works.

to encourage segregation and pre-treatment at source instead.

- *Negotiated - it should be impossible for any party (City, UW, industries) to unilaterally decide industrial effluent matters, whether it be tariff, by-laws, or the interpretation thereof. Industry will be more accepting of the proposed changes to industrial effluent control if an effective negotiating forum had been set up as part of the development of those proposals.*

SUGGESTIONS FOR NEW TARIFF

An assessment will be carried out every six months (as at present) and will be based on a minimum of four samples taken during the preceding six month period to represent the quality of industrial effluent discharged by a particular industry.

There will be five cost components to the tariff:

- *C = Conveyancing*
- *COD (or OA) = Treatment tariff based on organic load (preferably COD based, but OA as an alternative)*
- *OIL = Penalty for high concentrations of oil & grease*
- *P = Penalty for high concentrations of phosphate*
- *M = Penalty for high concentrations of metals*

Conveyancing may be a charge based on flow, which makes sense since the sewer pipes are designed on a flow basis. Hence C could be a factor in c/kl

Treatment costs based on COD (or OA) load will be a calculated sum for the six month period. This makes sense in view of the fact the aforementioned arguments in favour of load and the fact that the cost of wastewater treatment (or design for wastewater treatment) is mainly dependent on load.

Penalties for high concentrations of oil & grease, phosphate and metals will be six monthly lump sums, based on the industrial effluent quality observed by sampling. Since it is very difficult to link a given incident of high oil/ grease concentrations (or phosphate or metals) occurring in a sample to treatment costs at the Works, an overall link may be established whereby the cumulative costs of such incidents on a recurrent basis are converted into a

penalty tariff which serves as a disincentive for discharge of the problem substances to sewer; alternatively the penalty could be seen as an incentive for containment of the problem at source.

In overall structure, the tariff would be:

$COST (6 months) = [C \times (Flow \text{ for } 6 \text{ mo.})] + COD (Rands \text{ for } 6 \text{ mo.}) + OIL + P + M + pH$
 where OIL, P, M and pH are penalties (Rands for 6 mo.) - see below.

DERIVING THE INDIVIDUAL FACTORS FOR THE SUGGESTED NEW TARIFF

Conveyancing

The estimate of an equitable tariff for conveyancing would need to be calculated by the City Engineers Dept. in association with the City Treasurer. Ideally, this conveyancing charge should be based on the total flow from industrial effluent sources as a fraction of the total dry weather wastewater flow to Darvill, and then related to operating, renewal and capital cost of new sewers for the City. For example, if :

The cost for the operating, renewal and capital costs for sewers = Sewers (R/yr.); and

Fraction of industrial effluent (F) = [Total estimated industrial effluent flow, kl/yr.]/[Total dry weather flow to Darvill, kl/yr.];

then:

$Cost (c/kl) = 100 \times F \times [Sewers, R/yr.] / [Total \text{ estimated industrial effluent flow, kl/yr.}]$

If this conveyancing cost is included in the industrial effluent tariff, the "sewerage rates" component currently charged to industry should fall away.

Organic load based on COD (or OA)

A threshold daily limit of organic load should be set. As an example, the daily organic load equivalent to 20 000 g COD (20 kg COD) or 2000 g OA (2 kg OA) could be adopted. This would be based on the equivalent organic load derived from 200 people (100 g COD/person.d or 10 g OA/person.d). As a percentage of the approximate total organic load to Darvill, 20 kg COD (or 2 kg OA) would represent 0.1%. Such a limit would "net" about half of the ca. one hundred industries currently listed as industrial effluent producers in the bi-annual assessment for the City.

If the threshold is shifted upwards to 100 kg COD, this would represent 0.5% of the estimated total organic load to Darvill, and would "net" the twenty to thirty major producers of industrial effluent in the City.

Between these two approximate guidelines (ave. 20 to 100 kg COD/d or 2 to 10 kg OA/d), the threshold for classifying a industrial effluent producer must be set. The threshold must be reviewed from time to time, as the City grows.

Below the COD (or OA) threshold, a flat rate will be applicable, which will be also be applicable to all other consumers/ users in the City, including domestic users. If the City recovers costs for the Darvill Works from rates and a monthly sewerage, levy, then small/ light industries falling into this category should be charged in terms of that policy. This should also be the manner in which industries are billed for their domestic wastewater component arising from the number of employees, toilets on the factory premises, showers etc. It is imperative that each industry potentially producing industrial effluent continue to be visited, evaluated and the industrial effluent quality monitored if necessary, even if a given industry does not pass the COD load threshold for a particular assessment. The effluent quality and volume could change and then it could pass over the COD load threshold.

Above the COD (or OA) threshold, the industrial effluent tariff component will be based on the following formula which allocates treatment costs on a load basis. For COD, as an example:

COD cost (R/6 mo.)

= Y x 0.5 x [Darvill annual costs] x [Ave. Industry COD load]/[Ave. Darvill total COD load]

where

- Y is a factor determining the extent to which the load allocation principle will be applied. For example, in a case where the industrial effluent producers collectively contribute 30% of the total COD load to Darvill, but for reasons of cross-subsidy to industry, industrial effluent tariffs are only aimed at recovering 6% of the Darvill costs, $Y = 6/30 = 0.2$. This factor will need to be worked out after extensive negotiations between UW, the City administrators and representatives of industry;*
- 0.5 is the factor to break the annual costs into those for two six-month industrial effluent review periods per annum;*
- Ave. Industry COD load is calculated (in kg/d) from the average daily flow for the six month period (i.e. total estimated industrial effluent flow / no. of days in six month period) multiplied by the average COD from industrial effluent samples in that period. It will be*

imperative that at least four samples of industrial effluent per industry are obtained during the six-month period. In cases where flows are non-existent during the time of inspection by the Industrial Effluent officer, extraordinary measures may need to be taken to get samples (e.g. auto-samplers, inspections after normal office hours, or installation of a catch-pit in the line from which a grab sample will be taken).

- *The Darvill total COD load (average total load per day) will need to be reviewed on an annual basis to take into account growth in the City. Dry weather flow and COD data will need to be used in the calculation of this total load. The reason is that wet weather flows and CODs are unreliable and obscure the true load originating from wastewater (as opposed to rain or ground water) sources only.*

Oil penalty tariff

A threshold of max. 250 mg/l oil and grease is proposed (c.f. Table 1). If any one sample taken for industrial effluent monitoring purposes (including non-routine samples) is found to contain an oil and grease content greater than 250 mg/l, a penalty should be added to the tariff, subject to certain maximum amount per month of the period under assessment. The penalty tariff should be levied at the discretion of the City Treasurer under advice from the Industrial Effluent section of UW which does the monitoring. A penalty should only be levied for two (or more) months in succession if samples taken in each of the successive months showed > 250 mg/l oil and grease upon analysis.

The maximum monthly penalty tariff should be related in some manner to the additional costs of treating the effluent if it contains high concentrations of oil and grease. This cost may be derived from several sources:

- *Additional labourers (four on a full-time basis) = R5280/ mo.*
- *Process Controller Call-outs (two per month, 2h ea., overtime rate) = R400 / mo.*
- *Water Quality Dept., Call-outs (four per month, overtime rate) = R4000/ mo.*
- *Additional capital amortisation (over 20 years, 12%)*
- *PST oil skimmer system (R323 000 initial capital) = R 3600 / mo.*
- *Diminished sec. clarifier capacity (R1.4 million initial capital) = R16000/mo*
- *Additional alum for P removal (5 mg/l, 60 Ml/d) = R 9000 / mo.*
- *TOTAL = R 38 280 / mo.*

It may then be possible to "allocate" a penalty for the oil and grease on a sliding scale,

based on the highest oil and grease result obtained by monitoring in a given month. For example:

- < 250 mg/l = No Penalty
- 250 to 500 mg/l = R 12 000/ mo.
- 500 to 750 mg/l = R 25 000/ mo.
- >750 = R 38 250 / mo.

The maximum oil penalty payable under this sliding scale system (assuming six month assessment period and six samples, one in each month exceeding 750 mg/l) would be R229 500 for a six month period.

Phosphate penalty tariff

A six-monthly assessment of total phosphate load from each potential industrial effluent source should be made, independently of the COD (or OA) load. For each industrial effluent stream, for P penalty purposes:

Estimated TP load (kg/d) = Ave. Flow (kl/d) x max. TP concentration (mgP/l) / 1000

where the TP concentration is based on the maximum of at least four samples taken during a six month period.

The aim with the phosphate penalty tariff is to recover the costs for additional phosphate removal for excessively high loads of phosphate which exceed that normally present in the influent wastewater at Darvill. A threshold of 6 kg (or 6000 g P/d) is recommended, which is 1% of the normal load to Darvill. If any one (or more) sample(s) of industrial effluent give a (maximum) TP concentration and ave. flow which converts into a exceeds this amount, then it will likely result in significant additional costs for P removal at the Works. Hence, if the TP load from one industrial effluent source is > 6 kg P/d, the P penalty should be based on the additional chemicals used for P removal. This amount may be estimated as follows:

From research it is known that approx. 1.5 mol Al (as alum) is needed to remove 1mol phosphate. Hence approx. 14.4 kg as dry alum is required to remove 1 kg P.

Alum costs close to R1000 per dry ton, so it costs approx. R14 to remove 1 kg P with alum.

For any month in the period assessed, if any one or more industrial effluent samples taken (including non-routine samples) indicates an ave. TP load > 6 kg/d (see above), then for that month:

P penalty (in Rands/ mo.) = No. of days in month x [ave. industrial eff. TP load in kg/d -

$6] \times 14$

For example, if a industrial effluent estimate flow is 125 kl/d and the TP concentrations measured were as follows:

- Feb. sample = 40 mgP/l (load = $40 \times 0.125 = 5.0$ kg P/d)
- Mar. sample = 85 mgP/l (load = $85 \times 0.125 = 10.6$ kg P/d)
- Apr. sample = 67 mgP/l (load = $67 \times 0.125 = 8.4$ kg P/d)
- May sample = 44 mgP/l (load = $44 \times 0.125 = 5.5$ kg P/d)
- June sample = 55 mgP/l (load = $55 \times 0.125 = 6.9$ kg P/d)
- July sample = 39 mgP/l (load = $39 \times 0.125 = 4.9$ kg P/d)

then the estimated loads for March and April exceeded the 6 kg/d threshold and therefore will incur P penalties. The other months will not incur a P penalty.

The penalties will be:

- March : P penalty = $31 \times [10.6 - 6] \times 14 = \text{R}1996 / \text{mo.}$
- May : P penalty = $30 \times [8.4 - 6] \times 14 = \text{R}1008 / \text{mo.}$

Metals

A similar penalty system to that for phosphate needs to be worked out for metals. The impact of the metals is that they become mainly bound up in the sludge fractions and therefore limit the options available for sludge disposal. For example, if the metals content of the sludge is so high that it severely limits the agricultural application of compost made from the sludge, then the disposal costs will be higher since either the compost will need to be applied at a lower rate agriculturally to limit the metal loading on the soil to be cropped (i.e. the compost must be transported and distributed over greater areas, to more end-users in order to conform to the guidelines for its use in agriculture), or more expensive sludge treatment disposal routes would be required (e.g. incineration, which has a large capital and operating cost input including fuel, but produces an ash which can be disposed to landfill). At present, the sludge disposal for Darvill is "sacrificial" land disposal by irrigation onto about 50 ha. on adjacent land. This is the cheapest option available but has resulted in the loading rates for metals on this land exceeding the guidelines recommended by the Dept. of Health and endorsed by the Dept. of Water Affairs and Forestry.

As part of its strategic planning, UW is costing out various sludge disposal options for

Darvill. The current budget from the City only makes provision for the status quo (land irrigation of the sludge at Darvill). Based on the options selected and their sensitivity to metal content of the sludge, with the results assessment it should be possible to put estimate costs associated with a high metals content of the sludge. From this, a penalty tariff could be derived for failure for a given industry to meet prescribed limits for metals loads discharged via industrial effluent.

pH penalty tariff

The limits for pH defined in the by-laws (pH 6 to 9) could be enforced on the basis of potential damage to sewers. This would need to be worked out in consultation with the City Engineer's Dept. One method of calculating a penalty would be to "assign" an average length of connecting sewer (of an average diameter) to each of the major industrial effluent dischargers, and then calculate the monthly capital repayment costs on renewal of that length of sewer at shortened defined intervals (e.g. 5 years), which could result from accelerated corrosion (pH problems). For example, if a the assigned length of sewer costs R1000 per m to replace every 5 years, and the assigned length is 50m, then the cost per month (including 15% interest p.a.) could be R1250. Hence, if any one pH measurement for industrial effluent for a given industry during a given month is outside the required range, a fine of R1250 to that industry for that month could be justified.

The ultimate aims of effective industrial effluent control must be to develop a policy which:

- protects the treatment plant from persistent or wilful dumping of high strength waste to sewer in such a manner which compromises the capability of the Works to meet effluent discharge standards;*
- is equitable both to industry and the domestic consumer or ratepayer in terms of cost recovery;*

implements the principle of "The Polluter Pays" or "The User Pays" as far as is practicable.

In overall structure, an economic trade effluent tariff for 1997/1998 would be :

Including Conveyancing:

$$COST (c/kl) = 158 + (Ave. COD - 400) + \text{penalties for OIL} + P + M + pH$$

Excluding Conveyancing:

$$COST (c/kl) = 90 + 0.28(\text{Ave. COD} - 400) + \text{penalties for OIL} + P + M + pH$$

where:

Flow is in kl;

COD is in mg/l;

Penalties calculated in rands per month for specified months..