THE FEASIBILITY OF DESALINATION AS AN ALTERNATIVE MEANS OF WATER SUPPLY TO ZINKWAZI TOWN

Graham James Metcalf

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ABSTRACT

Desalination of seawater is a widely used technology throughout the world, but is not commonly used in South Africa for domestic water supply. The reasons for this are varied, but very often are based on the assumption that desalination is extremely costly in relation to more traditional water supplies. An economic analysis is undertaken comparing the cost of supplying water to the coastal town of Zinkwazi from various sources including desalination using reverse osmosis.

Zinkwazi has an existing borehole water supply that is insufficient to meet current and future demands. The town is also remote from regional bulk surface water infrastructure, which makes it suitable for the investigation of an alternative stand-alone water supply such as desalination.

Solving the water supply problems at Zinkwazi is important to Umgeni Water and would support two broad strategic goals of the organisation. Zinkwazi falls within the Ilembe District Municipality, which is an important stakeholder within Umgeni Water's area of jurisdiction. Improving the water supply situation at Zinkwazi is in line with Umgeni Water's goal of assisting Municipalities to meet their developmental objectives. Using desalination to meet this objective is in line with Umgeni Water's goal of using innovative products to alleviate problems of existing customers.

Desalination is a multi-billion dollar industry that is growing as traditional surface and goundwater resources become fully utilized and more polluted. Desalination potentially represents a growth opportunity that Umgeni Water, with its expertise in water treatment and supply, could pursue in Africa and Southern Africa in particular.

The investigation found that desalination is the most affordable method of supplying water to the town of Zinkwazi and the construction of a desalination pilot plant is recommended for further investigation.

DECLARATION

I declare that this dissertation is my own work, that is has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name: Graham James Metcalf **Date:** 16 May 2005

Signed: 

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Umgeni Water

Jesus Christ

The spring does not well up sweet and bitter water from the same cleft, does it? Nor is it possible, is it, my brothers, for a fig tree to bear olives, or for a grapevine to bear figs? Neither can salt water produce fresh water.

James 3:11

"If we could produce fresh water from salt water at a low cost, that would indeed be a great service to humanity, and it would dwarf any other scientific accomplishment".

John F. Kennedy 1954

NOTES

For the purposes of this dissertation the Rand Dollar exchange rate was taken as follows.

R1 = US$7

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ANNEXURES

1 INTRODUCTION

1.1 Background and Motivation

A well-established strategic perspective in business is that of Porter's Five Forces Model. Porter's "Five Forces" deals with the external pressures companies face in their business environment. The Five Forces are (Porter, 1979, cited in Pearce & Robinson, 2000, p.85) Competitors, Suppliers, Customers, Industry and Substitute Products. The last listed - Substitute Products - is of particular relevance to this dissertation. These forces exert varying pressures on a company, depending on the nature of the business and the circumstances surrounding that business at any particular time. For example, a Petrol Station experiences major market pressure from its suppliers. The oil companies set the price of petrol and Petrol Stations have to abide by these decisions. They do not usually have the option of buying cheaper petrol from other suppliers.

Similarly "Substitute Products" can exert pressure on, or pose a threat to, the continued success of a company's product. In the case of Umgeni Water, water is the company's product. Although there are no products that are substitutes for water, the method whereby potable water is produced can be varied. Alternative production methods include groundwater, wastewater recycling and desalination. Wastewater recycling and to a lesser extent desalination are of particular importance in terms of the potential threat they pose to Umgeni Water's revenue.

During 2001 Umgeni Water experienced a significant reduction in water sales, due to the commissioning of the southern wastewater recycling plant by Durban Water Recycling (Pty) Ltd, a public-private partnership. Within the first two months of commissioning approximately 33 Ml/d of wastewater was treated and sold to industry in place of municipal potable water. At that time it represented a direct loss in revenue for Umgeni Water of approximately R1.8 M/month (Umgeni Water, 2004, p.4).

Similar initiatives in desalination could further impact negatively on Umgeni Water's bottom line. Subsequent to pilot plant studies and feasibility investigations, both Thames Water (London) and the Water Corporation (Perth) announced in August 2004, that they plan construction of their first desalination plants within the next two years. The plant capacities are approximately 150 Ml/d and 120 Ml/d, at a cost of GBP 200M (R2.3bn) and A$ 346M (R1.6bn). Not only are these significant capital investments within the water industry, but the Perth Seawater Desalination Plant will be the biggest in the southern hemisphere (Umgeni Water, 2004, p.1).

The desalination market is a growing one, expected to generate expenditures of US$95 billion from 2005 – 2015, mostly in the Middle East (International Desalination Association News, 2004, p.4). Desalination is also being investigated in South Africa, especially in areas with water shortages such as Cape Town and Port Elizabeth (Sonjica, 2005, paragraph 4). The utilization of desalination is also no longer confined to arid countries as illustrated by its use in the United Kingdom. The abundance of surface water in KwaZulu-Natal compared to other provinces does not therefore automatically preclude the use of desalination in this province.

Umgeni Water has two organizational strategies that are of relevance to this study; these are:

Growth: To increase our geographic and development impact

- Establish Umgeni Water as a strategic role-player in achieving the objectives of development at local government.
- Position the commercial business of Umgeni Water as a significant strategic venture to meet the needs of its stakeholders.
- Develop Umgeni Water's regional, national, and international impact.

Customer: To continuously improve customer satisfaction whilst growing and developing our customer base in our primary business

- Seek innovative products upstream and downstream to alleviate problems for existing customers.
- Identify and develop new customers and markets for the primary business.

Desalination represents a growth opportunity for Umgeni Water, which at the same time can service the specific needs of some of the organisation's customers. Umgeni Water recently submitted tenders for two large desalination contracts in Algeria. Costs of desalination have decreased over the last decade and are now comparable in some cases to those of traditional water supplies. Breakthroughs in reduced energy costs and investment costs for desalination processes have resulted in cost levels of \$0.40 to \$0.80/m^3 (R2.8 to R5.6) before distribution

(Stikker, 2002, p.1). Another aspect that can reduce the cost of desalination significantly is when desalination plants are coupled with power plants to reduce energy costs, commonly known as co-generation (Pantell, 1993, paragraph 6).

Only a few South Africa companies possess expertise in desalination technology and therefore are able to tender for desalination contracts. Often expertise is sort from abroad whenever there is a potential desalination project. The global growth in the use of desalination and, particularly, the growth in demand for reverse osmosis systems, cannot be ignored by Umgeni Water. Expertise in this field needs to be developed or imported and a partner found that has already developed and marketed reverse osmosis technology. Consideration should be given to establishing a subsidiary company, specialising in desalination technology, which could be developed into South Africa's acknowledged leader in this market (Richards, 2000, p.23).

A possible way for Umgeni Water to establish a foothold in the desalination industry is for the organisation to gain practical experience, which can be facilitated by partnering with industry experts. A local desalination manufacturer with patented reverse osmosis technology was investigated as a potential partner to Umgeni Water. This dissertation investigates at a pre-feasibility level the viability of desalination at Zinkwazi by conducting an economic analysis. The economic analysis involves the comparison of various water supply alternatives to establish which is economically the most viable. Based on these findings it will be established whether Umgeni Water should investigate the construction of a desalination pilot plant at Zinkwazi.

Zinkwazi has been chosen because the town has a limited borehole water supply that cannot meet demand during peak or dry seasons, resulting in water restrictions being imposed periodically. The town's existing water supply therefore needs augmenting and alternative water supply systems such as desalination may provide the solution. The town is part of the Ilembe District Municipality, which is a municipality of strategic importance to Umgeni Water. Solving the town's water supply problem may assist negotiations between the two organisations concerning other larger bulk water supply issues.

Umgeni Water's Process Services Department, which runs a Process Evaluation Facility where pilot plants are designed, constructed and operated, has the expertise required to support this initiative within the organisation.

1.2 Objectives

The purpose of the research in this dissertation was to investigate whether desalination is an economically viable water supply alternative for Zinkwazi. The specific objectives of the research were:

- Investigate various water supply alternatives at a pre-feasibility level for Zinkwazi and estimate their cost.
- Investigate the potential of seawater desalination for Zinkwazi town.
- Undertake an economic analysis to establish the most economically feasible water supply alternative for Zinkwazi.
- Discuss the strategic possibilities of Umgeni Water implementing a desalination project at Zinkwazi as a first step in establishing itself in the desalination market.

1.3 Methodology

The following steps were followed in the execution in this dissertation:

- A literature review was undertaken to establish the global utilization of desalination in the water supply industry, the unit cost of producing water from desalination, the best desalination technology available and the future trends in desalination.
- The South African desalination market was scanned to determine the state of the industry and to find potential desalination service providers and examples of operational desalination plants. Information from operational desalination plants is particularly useful as it provides practical examples of construction and operation and maintenance issues for desalination plants in South Africa.
- A site visit to an operational desalination plant in the Eastern Cape was undertaken to obtain first hand practical information.
- Zinkwazi was chosen as a suitable town to investigate the feasibility of potable water supply from desalination.
- Water demand projections were made based on Zinkwazi existing consumption.

- Various water supply alternatives were evaluated as possible augmentation options.
- The cost of these alternatives was established at a pre-feasibility level, i.e. preliminary design and costing.
- An economic Net Present Value (NPV) analysis was undertaken to establish the least cost alternative.
- The findings of the investigation are presented and recommendations made on the way forward.

1.4 Chapter Outline

Chapter 2, **3** and **4** make up the literature review component of this dissertation. **Chapter 2** focuses on the status quo of water resources and the growing demand for water in the world today and in the future. It also touches on the various alternative water supply solutions for meeting this demand. **Chapter 3** reviews desalination technology, the cost of desalination and looks at trends in desalination technology that may have significant impact in the future. The last literature review chapter, **Chapter 4** focuses on South Africa's desalination experience and the application of this technology in South Africa.

Chapter 5 explains why Zinkwazi is of strategic importance to Umgeni Water and details the reasons why Zinkwazi is a suitable town for investigating desalination as a viable potable water supply alternative.

In **Chapter 6** desalination and a number of other water supply alternatives are investigated as a means of augmenting or replacing the existing borehole water supply to Zinkwazi. Pre-feasibility investigations were undertaken and costs of the various options provided for later use in an economic analysis.

Chapter 7 recommends the use of a particular locally manufactured reverse osmosis desalination technology and the reasons behind this choice. This chapter also elaborates on the specific details surrounding the practical application of desalination technology including the site location, plant configuration and environmental regulations.

In **Chapter 8** a pre-feasibility level economic comparative analysis was undertaken for the three alternative supply options. The assumptions and methodology applied to the NPV analysis are explained and the results presented.

Chapter 9 presents the conclusions of the investigation.

In **Chapter 10** the recommendations from this study are presented and a way forward proposed for Umgeni Water.

Chapter 2

2 STATUS QUO OF GLOBAL WATER RESOURCES AND SUPPLY

The literature review is separated into **Chapters 2, 3 & 4**. **Chapter 2** gives an overview of global water scarcity and the increasing demand for water. **Chapter 2** also highlights the global context within which this study takes place and proposes the utilization of alternative water supply technologies such as desalination to alleviate the water stresses faced by society.

2.1 Global Water Scarcity

After the air we breathe, water is indisputably the most essential resource the earth has to offer to the human race. Unfortunately, it is distributed throughout the world in uneven proportions as indicated in **Table 1** below (Thomas and Cuccinello, 1998, paragraph 1).

Table 1: Distribution of Water on Earth

Oceans:	97.23%
Ice caps and Glaciers:	2.14%
Groundwater:	0.61%
Freshwater Lakes:	0.01%
Other:	0.01%

Source: Thomas and Cuccinello (1998, p.1)

There have been three major drivers to the enormous expansion of water resources infrastructure in the past century (Refer to **Figure 1**): (1) population growth; (2) industrial development; and (3) expansion of irrigated agriculture (Gleick, 2000, p.2).

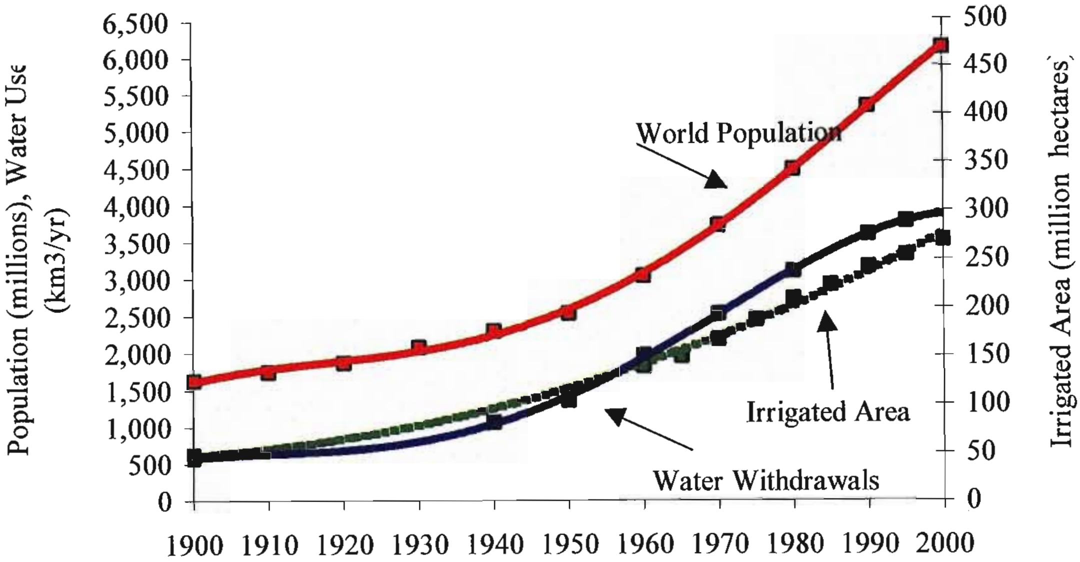

Figure 1: World Population, Water Use and Irrigated Area.

Source: Gleick (2000, p.2)

Postel, Daily and Ehrlich (1996, p.786) estimate that humans already appropriate 54 percent of accessible runoff on earth and if people continue with the policies of the 20th century, humans could be using more then 70% of accessible runoff by 2025. Harnessing these surface water resources through the construction of reservoirs will, however, become increasingly difficult since most of the best sites are already used, and considerable opposition to future development of reservoirs is being expressed in the developed countries.

Population growth, industrial development and rapid introduction of new technologies are changing the world we live in. Rising demands for water for municipal consumption, irrigated agriculture, and industry are forcing competition over the allocation of scarce water resources among different areas and types of use. Today 31 countries, accounting for 8% of the world population, face chronic water shortages. By the year 2025, however, 48 countries are expected to face shortages, affecting more than 2.8 billion people - 35% of the world's projected population (Simonovic, 2000, p.8). To meet the needs of a larger world population, the area of irrigated land will have to increase by 22%, and water withdrawals by 14% (Winpenny, 2003, p.2).

The threat of climate change and its effects on fresh water resources is also a matter of growing concern. Day (2000, p.4) states that we are basically unprepared for extreme climate events, which will increasingly destabilise regional agriculture, national economies and the lives of millions of people.

South Africa is due to run out of water between the years 2020 and 2030, according to former Water Research Commission executive director Piet Odendaal (Clancy, 1998, p.3) with an annual freshwater availability of less then 1000 m^3 per capita. Odendaal states that South Africa faces a water quality problem as well as a quantitative one. South Africa is already classified as a water-stressed country, as it has less then 1700 m^3 of water per person per year (Institute of Municipal Engineers of South Africa, 2001, p.4).

Within decades, most poverty will be urban poverty, and a dramatic manifestation of that poverty will be water shortage in cities, and increasing crises in water quality and quantity. The decline of health for urban children is already measurable. Where will we find water for these cities, many of which are already short of drinking water? US$170 billion per annum needs to be spent if the world is to address the problem of 1.2 billion people without water access (Catley-Carlson, 2002, p.3).

Former Department of Water Affairs and Forestry (DWAF) Minister Mr. Ronnie Kasrils believes we are moving into a future in which we must change, fundamentally, how we think about water. We are moving into a future in which we must recognise the physical limitations of water availability; in which we must recognise the devastating impact that we are having on the environment and on aquatic ecosystems (Kasrils, 2001, p.3).

2.2 Alternative Water Supply Options

As traditional water supply approaches become less appropriate or more expensive, unconventional supply approaches are receiving more attention. Large-scale projects can no longer be expected to provide the answer to most water problems. Major new projects must now compete with innovative smaller-scale, locally managed, technical, institutional, and economic solutions, including micro-dams, run-of-river hydro systems, shallow wells, land management and protection methods, and other locally managed solutions. In addition to this, non-traditional sources of supply will play an increasing role, including reclaimed or recycled water and desalinated brackish water or seawater (Gleick, 2000, p.5).

2.2.1 Efficiency

Efficiency of water use can be improved. This means meeting our needs with less water. Many cities are offering rebates for water-saving equipment and practices (Gleick, 1999a, cited in Water International, 1999, p.396). For example, all water supplied to the home can be used twice: for a primary purpose like washing or bathing, and secondarily for flushing the toilet or watering the garden (Davies and Day, 1998, p.8).

The potential for efficiency gains in irrigated agriculture is enormous (Gleick, 1999b, p.488).

2.2.2 Wastewater Recycling

Windhoek is world-famous for subsisting substantially on recycled water, and there is no intrinsic reason why this should not occur everywhere in southern Africa. In South Africa, we have been backward in fully developing recycling techniques because of public reluctance, official reluctance, rejection based on religious beliefs in some cultures and, most of all, because there has always been another river to dam. Non-domestic use of recycled water is, however, far more extensive and 193 million m^3 of which was used by industry and agriculture in South Africa in 1980 (Davies and Day, 1998, p.17).

According to recent studies by Environmental & Infrastructural Technologies (EIT) in China, the unit cost of recycled effluent from primary wastewater treatment plants with a capacity of 30 Ml/day or more would vary from US$0.03 to 0.57/$m^3$ (R0.21 to R3.99) depending on the intended usages of the recycled water. These cost figures do not include the distribution system costs, which vary widely according to the intended usages of the water. As the cost of developing new and reliable water supplies from traditional means increases, alternative water supplies such as desalination and wastewater reuse will gain wider acceptance in China in this decade (Chu and Chang, 2002. p.16).

2.2.3 Icebergs

There is more fresh water on this planet in solid form than in liquid and gaseous forms put together and so there is a need to consider the possibility of using icebergs as sources of fresh water. There are difficult technical and economic problems to overcome in using this great supply of fresh water. For instance, icebergs suitable for towing to shore would have to be large enough not to have melted on the way, and the ice would have to be liquefied, stored and possible transported inland. Each of these processes would be costly, so this potential source of water would be far from environmentally impact free (Davies and Day, 1998, p.24).

There is a dearth of information available on the feasibility of utilizing icebergs as a non-conventional water source. One study does, however, provide costs of non-conventional water sources and includes icebergs in this evaluation (Khordagui, 1996, cited in Abdulrazzak *et al*, 2002, p.403). The costs provided in **Table 2** indicate that utilizing icebergs is one of the least expensive forms of non-conventional water supply sources. If one considers that this study was performed for countries in the Arabian Peninsula that are geographically far from icebergs and where seawater temperatures are generally high, it may be worth investigating for countries closer to the poles, like South Africa.

Table 2: Cost of Non-Conventional Water Sources

Source of Water	US$/Cubic Metre
Tankers	1.250 – 7.500
Rubber bags	1.700 – 2.200
Desalination	0.500 – 2.500
Proposed pipeline	0.735 – 1.758
Water reuse treatment	0.070 – 2.200
Iceberg	0.020 – 0.850
Brackish desalination	0.400 – 0.800

Source: Khordagui (1996, p.403)

2.2.4 Desalination

With 70 % of the world's population living within 80 km from the oceans, seawater is an important source of water (Wicks, 1999, cited in Water International, 1999, p.396).

Growing populations along coastal areas provide an ideal opportunity to use desalination as a means of water supply. By 2025, megacities in these areas may be home to some 5 billion people (Stikker, 2002, p.1). Providing water from desalination will alleviate the stress on fresh water systems making more water available for agriculture and the needs of ecosystems.

Currently only one percent of the world's potable water is derived from desalination plants (Stikker, 2002, p.1). Stikker (2002, p.1) believes this small percentage has been influenced by negative sentiment towards desalination by the water industry. According to Stikker (2002, p.1) desalination has historically been considered:

- too costly, too large in scale, and technical for universal solutions:
- an impediment to awareness raising and efficient water management;
- as requiring an unacceptable level of fossil fuels.

Water scarcity in the future and the abundance of salt-water presents an obvious opportunity for reassessing desalination as a solution to providing an adequate, sustainable drinking water supply (Stikker, 2002, p.1).

In any country or region, the economics of using desalination is not just the number of dollars or rands per cubic metre, but also the cost of desalted water versus the other alternatives.

Desalination is becoming more attractive as a source of potable water as water demands steadily increase and the potential for new resource development becomes limited by availability and environmental constraints on new reservoir construction, (Wade and Callister, 1997, p.88).

Seawater desalination by reverse osmosis (RO) should no longer be considered a luxury, but thought of as a safe, economically viable, water supply alternative instead. The new, lower costs should profoundly affect planners and governments, both national and regional (Shields, 1999, p.20).

Costs of desalination have decreased over the last decade and are now comparable in some cases to those of traditional water supplies. It costs Umgeni Water R4.70/m^3 to produce water from its Hazelmere Waterworks on the North Coast of KwaZulu-Natal (Nichol, 2005). Breakthroughs in reduced energy costs and investment costs for desalination processes have resulted in cost levels of US$0.40 to US$0.80/m^3 (R2.8 to R5.6) before distribution (Stikker, 2002, p.1).

Recent and potential desalination developments indicate to Stikker (2002, p.2) that there will be substantial increase in the use of these technologies to produce fresh water from seawater and brackish water, but also from wastewater.

The costs of traditional methods of extracting and purifying surface water and ground water are increasing around the world, according to Stikker (2002, p.2). If the ecological costs of deeper wells and depleting surface water resources were taken into account, the cost picture would look worse.

Consulting engineers Ninham Shand believe that with advances in RO technology, RO is becoming a competitive process of water treatment which they expect will be used more and more in the future, both inland and at the coast in South Africa, (Tucker and Kritzinger, 1998, p.20).

United States of America Senator Mr. Paul Simon suggests that water desalination has to be part of the long-term answer to the problem of growing needs for freshwater supply of the world's population, which is expected to double in the next 40 to 90 years (Simon, 1999, cited in Water International, 1999, p.395).

2.3 Conclusion

Fresh water is not an abundant resource with only 2.77 % of global water being fresh, the rest being found in the oceans (Thomas and Cuccinello, 1998, paragraph 1). Competition and demand for water is increasing and it is predicted that by the year 2025, 48 countries and 2.8 billion people will be affected by water shortages, including South Africa (Winpenny, 2003). A change in our mindset has been called for by the former Minister of the DWAF, who states that we must recognise the physical limitations of water availability (Kasrils, 2001, p.3).

Alternative water supply solutions including improved water use efficiencies, wastewater recycling and desalination are increasingly being used. Due to continuous technological development desalination in particular is becoming more economically viable and increasingly common place. The proximity of large portions of the world's population who live in coastal towns and cities, make desalination an ideal water supply technology (Wicks, 1999, cited in *Water International*, 1999, p.396). The costs of desalination have reduced significantly and are comparable in some cases to traditional methods of water supply. From an environmental perspective the benefits of desalination over traditional methods add weight to the argument for is use (Stikker, 2002, p.1).

In summation, the factors mentioned above should, as Shields (1999, p.20) says, "profoundly affect planners and governments, both national and regional as they prepare to meet the water supply challenges of the future".

Chapter 3 discusses in detail the various types of desalination technology and some of their advantages and disadvantages. Desalination is presented as an economically viable alternative to traditional bulk distributed surface water resources, especially in coastal regions.

Chapter 3

3 DESALINATION

Chapter 3 discusses in detail the various types of desalination technology and some of their advantages and disadvantages. Desalination is presented as an economically viable alternative to traditional bulk distributed surface water resources, especially in coastal regions. Desalination is particularly cost effective when harnessed in conjunction with power generation, commonly known as cogeneration. A prime example of this is the proposed use of Koeberg nuclear power plant to provide energy for a desalination plant in the Western Cape. This and other cogeneration options have not been considered in this study, as there are too many unknowns at this level of research to make appropriate economic comparisons. For example, potential cogeneration facilities would have to be identified and in respect of nuclear power, they might be controversial energy sources.

3.1 History of Desalination

Desalting or desalination is a treatment process that removes salts from water, either brackish water or seawater to produce fresh water, usually for domestic or municipal purposes.

References to the desalination of seawater by distillation go back over 2000 years. Distillation processes, varying in complexity from simple pot stills to vertical tube evaporators, have been used since the 15^{th} century to meet shipboard requirements for fresh water (Buros, 1990, p.1).

In the modern era a major step in development came in the 1940's, during World War II when various military establishments in arid areas needed water to supply their troops. The potential that desalting offered was recognised more widely after the war and work was continued in various countries. The American government, through creation and funding of the Office of Saline Water in the early 1960's and its successor organizations like the Office of Water Research and Technology, made one of the most concentrated efforts to develop the desalting industry (Buros, 1990, p.1).

By the late 1960's commercial units were beginning to be installed in various parts of the world (Buros, 1990, p.2).

By the 1980's desalinations technology was a fully commercial enterprise. By the 1990's, the use of desalting technologies for municipal water supplies had become commonplace. Desalting equipment is now used in over 100 countries (Buros, 1990, p.4).

3.2 Types of Desalination

There are a number of different desalination processes, examples of which are discussed in detail in the following sections

3.2.1 Membrane Processes

Membranes are used in two commercially important desalting processes; electrodialysis (ED) and reverse osmosis (RO). Each process uses the ability of the membranes to differentiate and selectively separate salts and water. However, membranes are used differently in each of these processes. ED is a voltage-driven process and uses an electrical potential to move salts selectively through a membrane, leaving fresh water behind as product water. RO is a pressure-driven process with the pressure used for separation by allowing fresh water to move through a membrane, leaving the salts behind (Buros, 1990, p33).

3.2.1.1 Reverse Osmosis

When a salt solution is separated by a semi-permeable membrane from pure water, pure water will flow through the membrane diluting the salt solution. This process will continue until the hydrostatic head of the salt solution is sufficiently high to arrest the process. At this point the hydrostatic pressure is equal to the osmotic pressure of the salt solution, and is proportional to the total dissolved-solids concentration. Seawater of normal salinity has an osmotic pressure of approximately 25 bar.

If a pressure higher then the osmotic pressure is applied to the salt solution on the concentrate side of the membrane, a reverse flow will result in fresh water being forced through from the concentrated solution to the dilute solution. This process is known as reverse osmosis (RO). The rate of flow of pure water through the membrane is dependent upon the temperature of the water and the net driving pressure, the latter being provided (in practice) by a high-pressure pump (Wade & Callister, 1997, p.91).

There are three basic membrane types, namely cellulose acetate, polyamide and thin film membranes (Refer to **Annexure A**). To be useful, the membranes must be mechanically configured in a manner that is efficient and cost effective. Although other configurations are available, the two most widely used are hollow fibre and spiral wound (Refer to **Annexure A**) (Furukawa, 1999, p.260).

Except for regions where low energy prices prevail and/or where waste heat is available, RO is the most economical process for medium and large capacity seawater desalination plants, provided the seawater is not strongly polluted (Glueckstern, 1999, p.134).

It is generally accepted that feedwater quality has the strongest effect on the reliability and performance of RO plants. Seawater obtained directly from the surface always requires comprehensive pre-treatment such as media filtration, with or without chemical treatment and in many cases continuous or intermittent disinfection prior to final filtration (Glueckstern, 1999, p.130).

According to recent studies, the cost difference between desalinated water from a medium size SWRO plant fed with high quality seawater from beach wells and water from a plant fed by an open surface intake is in the range of 1.5 –2.0 in favour of beach wells (Glueckstern, 1999, p.134).

3.2.1.2 Electrodialysis

Electrodialysis reversal (EDR) is also a well-established membrane desalination technology where desalination is effected by removal of dissolved ions from the water under force of an electric field causing the movement of ions through ion exchange membranes (Ninham Shand, 2002a, p.8).

The applicability of electrodialysis in seawater desalination is however limited because of the excessive electrical power demand. Because ions are removed from water (as opposed to water being removed from ions, which is the case with reverse osmosis), the membranes are more resistant to fouling than reverse osmosis membranes. If fouling does occur, it is possible to disassemble the membrane stack for cleaning. However, salt rejection is not as good as that achieved by reverse osmosis and the quality of the diluate produced by electrodialysis is generally not as good as the reverse osmosis' permeate. The nature of the electrodialysis process means that non-ionic impurities such as organics are not well removed and remain in the diluate at higher concentrations than were present in the feed water. This higher concentration in organics can result in problems in use or in subsequent second stage membrane treatment (polishing).

Electrodialysis is less susceptible to scaling problems than reverse osmosis, but similar precautions are normally taken. Electrodialysis plants must be installed indoors.

Pre-treatment is often necessary to prevent microbial growth on the inner surfaces of the membrane stack, and chlorination - dechlorination pre-treatment is often used.

The membranes are flat sheets, usually made of plastic film, formed on a fabric backing to provide strength, with ion transfer sites added to the membranes to give each type the required selectivity to pass either cations or anions. Cation membranes generally consist of cross-linked polystyrene that has been sulfonated to produce fixed ionic charges in the membrane. Anion membranes have quaternary ammonium groups fixed in a similar cross-linked polymer (Ninham Shand, 2002a, p.8).

One pair of electrodes is required for each electrical stage. The electrodes are generally constructed of niobium or titanium with a platinum coating.

The extent to which the feed water is desalinated in each stage depends on the residence time in the stage and the current density. Current densities are kept as high as possible to improve desalination. The actual current flow is limited by the high electrical resistance when the ionic concentration of the water is sharply reduced.

Only ions are removed from the feed water and organic materials thus remain in the product water.

3.2.2 Thermal Distillation Processes

The distillation process consists of heating the influent saltwater until it boils. This will separate out the dissolved minerals resulting in a purified and salt-free product. This product is then captured in its gaseous state, with high efficiency, and piped out to the distribution system. The three main distillation processes are separated according to their heat source. These processes are multistage flash distillation (MSF) in which the latent heat comes from the cooling of the liquid being evaporated, multiple-effect distillation (MED) in which the latent heat comes from a solid surface, and vapour compression distillation (VC) in which the latent heat is obtained regeneratively (Thomas and Cuccinello, 1998, paragraph 5). A detailed explanation of these three processes is provided in **Annexure B.**

Distillation is often not considered due to the lack of an economically viable heat source (waste heat). However, the process has a number of advantages, for example:

- it is a "robust" process, and is flexible in being able to handle varying feed water qualities;
- although it is susceptible to scaling, this is relatively easy to clean using suitable chemicals;
- operating costs are low where excess heat is available; and
- distillation plants could be located outside (i.e. no buildings are needed).

The quality of the product water is generally better than 100 mg/l total dissolved salts (TDS), irrespective of the feed water quality. A recovery rate of 85% and more is normally achieved with seawater as feed (Ninham Shand, 2002a, p.7).

3.2.3 Other Processes

The following processes are not used commercially to any great extent, but they are important for specific circumstances or niche markets where the application of more efficient but capital-intensive desalination technologies are not economically feasible.

3.2.3.1 Ion Exchange

Unlike other desalination processes described here, ion exchange does not remove all salts in equal, or roughly equal, proportions. Ion exchange is used to target and remove a particular problem ion in water e.g. Calcium (Ca^{2+}) in the case of an excessively hard water (cation exchange), or NO_3^- in the case of water having too much nitrate (anion exchange). The removed ion changes places with anion from the ion exchange resin, often Sodium (Na^+) or Chlorine (Cl^-) (Still, 1992, p.2.11). In desalination applications cations are exchanged for hydrogen ions and anions for hydroxl ions in a two-bed system, and if very low concentrations of dissolved solids are required this may be followed by a mixed bed exchanger (Schutte, 1983, p.26).

Ion exchange resins have a finite capacity and must therefore be regenerated to restore ion exchange capacity (Schutte, 1983, p.26).

A number of municipalities use ion exchange for water softening, and industries requiring extremely pure water e.g. power station boiler feeds, commonly use ion exchange resins as a final treatment following reverse osmosis or electrodialysis. The primary cost associated with ion exchange is in regenerating or replacing the resins. The higher the concentration of dissolved salts in the water, the more often the resins will need to be renewed. In general, ion exchange is rarely used for salt removal on a large scale (Richards, 2000, p.18).

3.2.3.2 Solar Distillation

The sun's energy is used to heat the saline water, some of which evaporates. The vapour circulates by convection to a cooler surface where it condenses and is collected. Distilled water is produced in this way. Usually the whole process of evaporation and condensation is integrated into one container, typically a basin with a pitched glass cover (Still, 1992, p.3.8).

Typically 20 to 50 % of the daily solar radiation is utilized for evaporation of distillate, the balance being lost through reflection and radiation from the water and glass cover, and through losses to the ground beneath the still (Still, 1992, p.3.8).

Maximum production is reached in mid summer, when the daily solar radiation is at its greatest. On clear days 5 l/m^2 of still area can be produced. In wintertime, depending on latitude, production in horizontal basin stills decrease to below 2 $l/m^2/d$ on average. Unlike other desalination processes, solar distillation is insensitive to the salinity of the feed water (Still, 1992, p.3.20).

Solar distillation has the following difficulties, which restrict the use of this technique for large-scale production:

- Large solar collection area requirements
- High capital cost
- Vulnerability to weather-related damage

An application for these types of solar humidification units has been for desalting saline water on a small scale for families or small villages where solar energy and low cost or donated labour is abundant, but electricity is not (Buros, 1990, p.43). South Africa currently has two operational solar desalination plants supplying potable water to the small communities of Kerkplaas and Algerynskraal, in the arid Klein Karoo region of the Western Cape (Le Roux, 2004, paragraph 6).

3.2.3.3 Freezing

Desalination by means of freezing is based on the natural phenomenon that ice crystals are made up of pure water. Any impurities such as dissolved solids are excluded from the crystals and therefore when melted, the ice crystals yield pure water. Freezing resembles distillation in that a change of phase is involved but it has a number of advantages over distillation: it requires the transfer of less energy; needs almost no pre-treatment and has minimal corrosion problems. Despite these advantages and research and development work since the 1950's seawater desalination by freezing has not become a commercial success (Schutte, 1983, p.85).

Problems encountered in freezing include handling and separation of the ice-brine slurry and washing the ice crystals free of salts.

There are four basic elements in all freezing desalination processes viz. freezing, washing, melting and heat removal.

At this stage, freeze-desalting technology probably has better application in the treatment of industrial wastes than in the production of municipal drinking water (Buros, 1990, p.42).

3.2.3.4 Membrane Distillation

Membrane distillation was introduced commercially on a small scale during the 1980s, but it has demonstrated no commercial success. As the name implies, the process combines both the use of distillation and membranes. In the process, saline water is warmed to enhance vapour production, and this vapour is exposed to a membrane that can pass water vapour but not liquid water. After the vapour passes trough the membrane, it is condensed on a cooler surface to produce fresh water. In the liquid form, the fresh water cannot pass back through the membrane, so it is trapped and collected as the output of the plant.

The main advantages of membrane distillation lie in its simplicity and the need for only small temperature differentials to operate. This has resulted in the use of membrane distillation in experimental solar desalting units. However, the temperature differential and the recovery rate, similar to the MSF and MED processes, determine the overall thermal efficiency for the membrane distillation process. Thus, when it is run with low temperature differentials, large amounts of water must be used, which affects its overall energy efficiency (Buros, 1990, p.42).

3.3 Other Aspects of Desalination

3.3.1 Cogeneration

Cogeneration is a process in which exhaust steam from electricity generating plants is used for another purpose. If a desalination plant uses cogeneration to supply part of its energy needs, the plant could reduce its demand for power. For example, a distillation plant can use the heat in a power plant's exhaust steam to evaporate feedwater. A cogeneration power plant that operates with a distillation plant, however, must be specially designed for that purpose (Pantell, 1993, paragraph 6).

Other options for cogeneration is in a hybrid plant that uses both RO and distillation (e.g. MSF) technologies. Existing power stations can be "retrofitted" in the evaporators and RO units to achieve a hybrid plant, thus eliminating the need to construct a new desalination facility. The MSF plant draws waste steam from a thermal power station and uses the energy in the steam to preheat seawater, which is then distilled in the MSF unit. The RO unit uses electricity from the power station and operates during periods of reduced power demand, thus optimising the overall efficiency of the entire operation. Advantages of the hybrid design include: reduced energy costs and reduced capital costs and operating costs from reuse of cooling water, feedwater or steam (Pantell, 1993, paragraph 6).

3.3.2 Energy recovery devices

An efficient Pelton-type turbine can yield a saving of more then 40% of energy usage, while a pressure exchanger is even more effective and can save about 50% on small desalination systems. For larger systems (5,000-10,000m^3/d) the comparative performance of a hydraulic turbine is much improved because of the higher energy recovery turbine efficiency at higher flows (Glueckstern, 1999, p.132).

3.4 Economics of Desalination

Providing general estimates for the cost of desalinated water is difficult because of the variability of factors involved in capital and operating costs, which are dependent on the type of plant, plant location, feed water quality, labour, energy, financing, environment and plant reliability. Any costs provided are thus relative to all these factors and more accurate costs can only be provided following a site-specific pre-feasibility study. Bearing this in mind the potential costs of various types of desalination have been extracted from the literature to provide "ball-park" figures for comparison with other more traditional forms of water supply.

The cost of desalinated water has been dropping dramatically over the last 20 years to the point that it is now less than half of what people are paying in some major urban areas (Pique, 2002, p.9). **Figure 2** below shows how the historical cost of producing and buying desalinated water has been decreasing over the years.

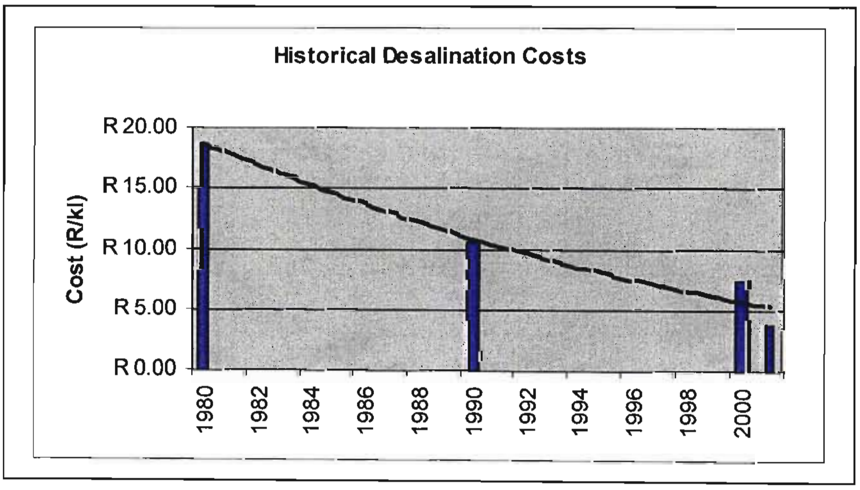

Figure 2: Cost to produce and sell 1 m^3/d of potable water from seawater.

Source: Pique (2002, p.9)

The costs of desalinating seawater have dropped below R5/m^3 since 2001 as illustrated in **Figure 2** above. These reported costs are supported by the following: -

- The Saudi Arabian Water Saline Conservation Corporation (SWCC) estimates that its weighted average water production costs are $ 0.67/m3 (R4.69).
- Recent RO BOOT projects in Tampa Bay, Florida, Point Lisas Industrial Park, Trinidad and Tobago, and Larnarca, Cyprus had contracted water prices of US$0.46 (R3.22), US$0.71 (R4.97) and US$0.73/m3 (R5.11), respectively (Kappaz, 2002, p.13).

The following can also be noted as being important facts regarding the economics of desalination (Abdulrazzak, Jurdi & Basma, 2002, p.396): -

- Energy costs account for about 20 to 30 % of water production cost using international energy prices.
- For small plants, automation may decrease the number of operators required but not necessarily their cost, inasmuch as more qualified staff will be required.
- Desalination plants require major initial capital outlays that need to be depreciated over plant service life, which could be 30 years or more. Hence, the cost of capital has a significant impact on unit water cost since capital contribution is about 30 to 60 percent of unit water cost. A recent analysis (Al-Sofi, 1993, p.5) of actual bid data for a large MSF desalination plant in the Gulf indicates a large variance of the capital contribution to unit water cost over plant life, which was specified as 25 years.
- In general costs decrease with increase in plant capacity.
- Desalination costs in Economic and Social Commission of Western Asia (ESCWA) member countries, can be distributed as follows:
    - 38 % for capital investment
    - 20.5 % for energy
    - 21.3 % labour
    - 16.2 % maintenance
    - 4 % chemicals

3.4.1 Cost Comparisons

The apparent cost difference between 'natural' and desalinated water can arise because capital costs of reservoirs, pumping stations etc have been amortised and are no longer included in the calculation. Figures quoted for desalination include capital costs, fixed and variable. Weir

Westgarth Ltd's marketing director Mr. Bill Stewart makes the point that many water companies, when they cost a water supply and look at the capital cost, will only allow for the treatment of water, not the 'creation' of it (Arthur, 1997, paragraph 9). In contrast, the suppliers of desalination plants cover all costs of 'creating' freshwater from seawater, as well as treatment. A truer comparison of costs is between desalinated water and the development of 'new' water supplies.

Table 3 adapted from Bögeholz (2000, p.3) compares the costs of supplying an additional (marginal) kilolitre of water at the wholesale delivery point for, both desalination plants and traditional 'roman-technology' bulk water supply.

Table 3 Examples of costs (prices) of supplying additional kilolitre of wholesale water.

Technology	Ml/d	Per Kilolitre A$ 1 A$ = R4.25
1. Reverse osmosis (1)	27	2.75
2. Reverse osmosis (2)	20	1.42
3. MED solar powered from waste heat from a 21 hectare solar thermal 275 dish electric power plant (3), electricity sold @ A$ 0.6 kWh.	20	1.45
4. MED solar powered from waste heat from a 10.5 hectare solar thermal 275 dish electric power plant (3), electricity sold @ A$ 0.12 kWh.	20	0.95
5. Composite: Co-generation and Reverse Osmosis Desalination Plant (4).	20	1.44
6. Roman Technology, average bulk (5) Surcharge Add Capacity Charge – Basic annualised (6).		0.54 0.11 1.16 1.81

Notes:

(1) Existing facility, City of Santa Barbara USA

(2) EWS Feasibility Study, Coffs Harbour, Australia. NSW Govt. Publications, Sydney.

(3) EWS Feasibility Study, Coffs Harbour, Australia. NSW Govt. Publications, Sydney. Capital expenditure: MED plant A$ 52,000,000; Solar Thermal Plant A$ 55,000,000; Land A$ 5,000,000; Other: A$ 22,330,000. Fully written down over 30 years, 7% interest; Operations & Maintenance A$ 3,390,000; Electricity sales @ A$0.06 kWh

(4) EWS Feasibility Study, Coffs Harbour, Australia. NSW Govt. Publications, Sydney. Capital expenditure: MED plant A$ 22,500,000; Reverse Osmosis Plant A$ 19,000,000; Solar Thermal plant: A$ 24,000,000; Land A$ 2,500,000; Other: A$ 17,930,000. Fully written down over 30 years, 7% interest; Operations & Maintenance A$ 3,710,000; Electricity sales @ A$0.12 kWh

(5) Water provider: Metropolitan Water District Of Southern California. Rate per kilolitre A$ 0.54 assuming 200 kilolitres used per year

(6) Water wholesaler: San Diego County Water Authority Surcharge A$ 0.11. Capacity charge A$ 1.16 per additional connection, meter size, less then 1 inch. Annualised over 30 years, 7% interest: per year, 200 kl use per year.

Source: Bögeholz (2000, p.3)

Except Example 1, all examples in **Table 3** include pumping installations, pipes and a 10 megalitres storage tank. Example 3 is a combined solar electricity generation and water distillation plant that produces more energy than it consumes. The economics of this plant are very sensitive to the price that could be obtained from sales of the electricity generated. Cost per kilolitre of water would fall from A$1.45 to A$0.95 if the price per kWh of electricity sold increased from A$0.06 to A$0.12, as indicated in Example 4. Example 5 combines electricity production and water distillation using solar power with a reverse osmosis plant to supply desalinated water. Example 6 reflects the costs of providing additional supply to a new connection using the 'roman system'. Treated water is provided by the Metropolitan Water District of Southern California (MWD) at a price of A$ 0.54 to wholesalers (this price may not be based on current replacement value and may not include all costs of capital). A wholesaler, for example the San Diego County Water Authority purchases water from the MWD and adds a surcharge of A$ 0.11, and a capacity charge of A$ 1.16 per new connection of meter size lower than 1 inch. This capacity charge when annualised and added to the surcharge and MWD purchase price results in a wholesale price of A$1.81 per kilolitre for consumption by a new meter connection using about 200 kilolitres per year. The San Diego County Water Authority sells wholesale water to retailers such as the Water Department of the City of San Diego for distribution. Therefore the A$ 1.81 per kilolitre at the wholesale level is more comparable with the prices of additional water supplied from desalination plants also at the wholesale level, as in both cases retailing distribution costs to be incurred by retailer municipalities are excluded (Bögeholz, 2000, p.3).

3.4.2 Local Circumstances

Combinations of local factors can also decisively affect the economics of desalination. Anglian Water in the United Kingdom has a long coastline and its many visitors create a high summer demand. The infrastructure to meet this by extra water transfers would be expensive if it were needed for only four months of the year. The relatively high cost of meeting seasonal demand from seawater could be balanced against the high cost of measures to increase inland reserves (Arthur, 1997, paragraph 12).

The economics of desalination is therefore very often site-specific. A system like desalination, which can be switched off, is ideal for meeting seasonal demand.

3.4.3 Financing

Financing of water projects in Sought Africa is faced with two major problems. Firstly, water projects are generally capital intensive and require a high initial investment that is normally beyond the means of most Municipalities. Secondly the massive backlogs in water service provision in South Africa make the demand for funding great and therefore difficult to obtain. It is estimated that in KwaZulu-Natal alone R900M per annum is required to meet the basic water needs of the un-served (Umgeni Water, 2004, p.4).

Municipalities as defined by the Water Services Act (108 of 1997) in Section 11 are legally responsible for water services provision within their area of jurisdiction. If Municipalities cannot afford to fund water projects then other sources of funding are required. Alternative finance mechanisms, such as government grant funding, Build Own Operate (BOO) or international soft loans may have to be sourced.

With respect to international loans, the main problem is risk of investment in developing countries, which is a general constraint on international finance, not limited to the water sector. Very few emerging markets have investment ratings that enable them to raise funds on attractive terms. South Africa is, however, fortunate enough to be one of these exceptions with an investment rating of Baa2. The international ratings agency Moody's is reviewing this rating for a possible upgrade to Baa1, a rating that is two notches above investment grade (Joffe and Seria, 2004, paragraph 4). This improvement in South Africa's sovereign ratings would make it cheaper to borrow on international markets.

Water projects have the additional disadvantage that there is a high minimum size of project finance, due to the size of legal costs and the terms for water projects. International project finance has large returns to scale because of the legal, financial and due diligence costs associated with it. Many water projects may not be viable for project finance because they fall below the minimum size for it (Winpenny, 2003). It is therefore probable that the best opportunity for raising finance in South Africa would be through national funding vehicles such as the Municipal Infrastructure Grant (MIG).

3.5 Advances in Desalination

In 1962, the energy requirement to desalinate 1 m^3 of water was 24 kWh. In 1998, this requirement had decreased to 2.9 kWh/m^3. The theoretical requirement is approximately 0.53 kWh/m^3. The reduction in energy requirement is largely due to the invention of RO (Leitner, 1999, cited in Water International, 1999, p.396).

Birkett (1999, cited in Water International, 1999, p.396) and Furukawa (1999, p.261) highlight's the following advances in desalination, both in capital and operating efficiency including: -

- RO spiral membrane element costs now 10 times less than 20 years ago.
- The rate of salt rejection is seven times better and membranes have been improved by a factor of 100.
- The reliability of the desalination systems and energy consumption has also improved.
- Improved energy recovery systems
- Improved pre-treatment methods and chemicals
- Hybrid systems

3.5.1 Trends

Reverse osmosis is the fastest growing and appears to be achieving a position as the "process of choice" for new plant construction.

To date, the principal users of RO plants are municipalities (Farukawa, 1999, p.259). More then 79% of the seawater plants are installed by municipalities (Refer to **Table 4**).

Table 4: Users of SW Membrane Plants

User	Percentage
Municipal	79%
Industrial	15%
Power	3%
Military	2%
Others	1%

Source: Furukawa (1999, p259)

3.5.2 New Technology

- A South African company (GrahamTek (Pty) Ltd) has developed a new system, which vastly improves the flow distribution across the membranes using a patented flow distribution technique. It achieves greater efficiency by reducing the hydrodynamic boundary layer conditions at the membrane surface, enhancing both membrane flux and apparent rejection (Kalish, Graham, and van Vugt, 1997, p.1).

  In addition the system utilizes a unique electromagnetic device, which surrounds the membranes. In do doing, it affects both ionic and organic species in the feedwater, deterring both precipitation and membrane fouling, thereby eliminating chemicals from the process, both pre-treatment and post-treatment (Furukawa, 1999. p.262).

- New desalination technology known as Rapid Spray Evaporation (RSE) is expected to deliver fresh water at R2.64/m^3 including equipment, processing, operational overhead and capital investment (Lloyd, 2002, p.16). This is on a par with bulk water tariffs charged by water service providers such as Umgeni Water. The technology is, however, still in the developmental phase with only small units capable of producing 11 m^3/day of potable water having been developed.

- New SWRO plants are generally built with advanced alloys like Titanium, AL6XN, 254 SMO, Zeron 100, or "Super Duplex" alloys. These are suitable for SWRO applications (Pique, 2002, p.9), as they are resistant to corrosion and therefore reduce O&M replacement costs of infrastructure.

New advances in RO technology have the promise of reducing both capital and operating cost for the process. It is believed that improvements will continue that will allow construction of small systems to become an economically viable choice (Furukawa, 1999, p.263).

3.5.3 Focus of Future Research

The U.S. Defence Department continues to investigate low-power highly efficient concepts for water purification and desalination such as cavitation, pulsed reverse osmosis, pressure recovery, computational fluid mechanics, spacer geometry (molecular geodesics), smart chemistry and surface roughness (Warren, 1999, cited in Water International, 1999, p.397).

The United States (US) of America Water Desalination Act of 1996 addresses the fundamental need in the US and worldwide for additional sources of potable water. The programme aims at developing more cost-effective, technologically efficient, and implementable means to desalinate water. Two major areas of emphasis are on membrane technology and energy recovery and reduction.

Other technologies being developed and tested include Ocean Thermal Energy Conversion (OTEC). OTEC is very promising as an alternative energy source for tropical areas. OTEC plants could potentially provide inexpensive power and desalinated water, and mariculture products. System analysis indicates that a 2 MW (electric) (net) plant could produce about 4300 cubic meters of desalinated water each day (National Renewable Energy Laboratory, 2004, paragraph 1).

3.6 Conclusion

Desalination is a proven water treatment technology used in over a 100 countries. Desalination technology can be divided into two broad categories namely, membrane processes and distillation. Membrane processes use the ability of the membranes to differentiate and selectively separate salts and water. The distillation process consists of heating the influent saltwater until it boils. This will separate out the dissolved minerals resulting in a purified and salt-free product. This product is then captured in its gaseous state, with high efficiency, and piped out to the distribution system.

Except for regions where low energy prices prevail and/or where waste heat is available, RO is the most economical process for medium and large capacity seawater desalination plants, provided the seawater is not strongly polluted (Glueckstern, 1999, p.134).

The cost of desalinated water has been dropping dramatically over the last 20 years to the point that it is now less than half of what people are paying in some major urban areas. The cost of desalinating seawater has dropped below R5/m^3 since 2001 (Pique, 2002, p.9).

South African company (GrahamTek (Pty) Ltd) has developed a new system, which vastly improves the flow distribution across the RO membranes using a patented flow distribution technique. It achieves greater efficiency by reducing the hydrodynamic boundary layer conditions at the membrane surface, enhancing both membrane flux and apparent rejection (Kalish, Graham, and van Vugt, 1997, p.1). The Albany Coast Water Board is currently using this RO technology in a desalination plant supplying municipal water. A site visit to this plant was undertaken in order to view this technology first hand and to obtain information on the practicalities of operating a desalination plant. The findings of this site visit are discussed in **Chapter 4**.

CHAPTER 4

4 DESALINATION IN SOUTH AFRICA

Chapter 4 details the historical and current application of desalination in South Africa. Desalination is, however, an extremely small industry in South Africa and therefore information gathering of practical experience and costs was limited. A site visit to an operational desalination plant in the Eastern Cape did, however, provide valuable information.

4.1 Past experiences / research

Schutte (1983, p.10) looked at the potential application of desalination for domestic water supply in South Africa. He indicated that desalination represented a viable water supply alternative for small to medium sized towns in some cases. Towns that fell into one of two categories were of particular relevance. Firstly, isolated coastal towns with inadequate water supplies that had to meet high seasonal demands brought about by holidaymakers. Secondly, inland towns, that potentially would have to obtain a large proportion of their water from brackish groundwater to meet increasing demands.

Schutte makes mention of towns such as Calvinia, Port Alfred, and Robben Island, among others as potentially using desalination in the future. Although Port Alfred is still supplied from surface water, the adjacent holiday resort of Kenton-on-Sea now obtains half its water from the desalination of seawater. Robben Island a popular tourist attraction obtains all its water from the desalination of seawater.

Schutte also suggested larger towns and cities such as Beaufort West, Graaff-Reinet and Cape Town may be using desalination by the year 2000. Although this has not materialized Cape Town is considering desalination as a potential water supply alternative. The City of Cape Town (CCT) has conducted feasibility studies into the feasibility of co-generation desalination using Koeberg nuclear power station.

The first municipal desalination plant in South Africa was installed at Bitterfontein / Nuwerus in the Cape Province in the early nineties. The plant was a RO plant and had a capacity of 150 m^3/d, (Still, 1992, p.1.3). The cost of the desalination plant was R12.05/m^3 for capital amortization at 17.25%, and R6.97 for operation and maintenance, for a total of R19.03/m^3. This figure was expected to half once the plant became fully operational, which it never did.

4.2 Industrial purposes

Desalination for industrial purposes is well established in South Africa. Ion exchange is mostly used to supply water of very low Total Dissolved Solids (TDS) concentrations for uses such as boiler feed water and for the manufacturing of specialized electronic and other equipment (Schutte, 1983, p.17).

At Sasol's Secunda petrochemical works, a process consisting of pre-filtration, pH control and tubular RO membranes are installed to desalinate the effluent for re-use in the factory. A total of 6000 m^3 of high quality permeate is recovered per day (Water Research Commission, 2002, p.1).

4.3 Small-scale desalination

Still (1992, p.2.3) investigated the economic feasibility of various desalination processes to address the potable water needs of households and other low demand users. His conclusions are summarized in **Table 5,** which suggest demand ranges at which the various technologies might best apply.

Table 5: Suggested economic capacity ranges for competing desalination technologies, depending on circumstances.

Desalination	Suggested Capacity Range (l/d)	Favourable indicators for use
Solar Distillation	2 - 200	No electricity supply, very salty water (e.g. seawater), high sunshine levels, low skills base
Electrodialysis	100 - 5 000	Feed water TDS < 5 000 mg/l, high skills base, availability of electricity
Reverse Osmosis	> 3000	Availability of electricity, medium skills base, feed water TDS < 10 000 mg/l
Ion Exchange	> 100	Specific problem (e.g. NO_3^-) as opposed to overall TDS problem, high skills base

Source: Still (1992, p2.3)

4.5 Reference Plant Visit

Two seawater desalination plants are currently operational in South Africa for potable water supply. One of the plants is on Robben Island and the other at Albany Coast Water Board (Bushman's River), was visited as part of this study. **Table 6** below summaries the salient features of these two desalination plants. A report on the site visit is contained in **Annexure C**. A summary of the significant findings of the report and how they provided input into this study are provided below.

Table 6 Comparison between South African desalination plants

Location	Robben Island	Albany Coast
Owner	Public Works Department	Albany Coast Water Board
Intake structure	Open sea intake	Beach wells
Pre-treatment	Sand filter, iron removal, etc.	Cartridge filters
Post treatment	Chlorination, blending	Chlorination, blending
Type of plant	Reverse osmosis	Reverse osmosis
Capacity (product water)	21 m^3/h (0.5 Ml/d)	62 m^3/h (1.5 Ml/d)
Recovery	43 – 50 %	45%
TDS (feed water)	35 000 – 38 000 mg/l	22 500 mg/l
TDS (product water)	520 – 650 mg/l	300 mg/l
Energy recovery device	No	Yes

Source: Table adapted from Ninham Shand (2002b, p.12)

The Albany Coast Water Board (ACWB) site visit was important in that it provided valuable practical information. The desalination plant manager Mr. Ron Ball was able to relate undocumented information on his experiences of operating and managing the plant. These lessons will prove useful to Umgeni Water or any other organisation wishing to implement a desalination project. Some of the key points were:

- The seawater is abstracted from beach wells which have the advantage of the sand providing a natural filter that eliminates the need for pre-treatment at the plant providing a cost saving. Beach wells are a preferred source of seawater for RO plants, compared with an open seawater intake (Abdulrazzak *et al*, 2002, p.400). The disadvantage of this system is that the abstraction rate is limited by the transmissivity of the sands and the number and diameter of the wells.
- The cost of producing water from desalination at ACWB is R4.50/kl, which although double Umgeni Water's bulk water tariff should be considered in light of the fact that there are no other reliable sources.
- The plant manager stressed the importance of addressing social and environmental issues upfront with respect to any desalination development to avoid problems as generally consumers and ratepayers were ignorant about desalination and especially the brine disposal.
- The plant has been operating successfully for six years using locally produced desalination technology. The manufactures of the desalination technology, GrahamTek (Pty) Ltd may therefore represent a potential partner or service provider to Umgeni Water.

4.6 Conclusion

Desalination for domestic water supply in South Africa is very limited with only two desalination plants namely, Albany Coast Water Board (ACWB) and Robben Island. The use of desalination for industrial purposes is, however, well established (Schutte, 1983, p.17).

The ACWB site was visited as part of this study and invaluable information was obtained. The ACWB uses locally produced GrahamTek desalination technology and has been operating successfully for six years. This was important to establish as Umgeni Water is looking for potential desalination service providers and therefore the track record of these service providers and the performance of their technology is critical.

The significance the environment and social issues was also apparent from this site visit and careful consideration and attention should be given to these aspects when proposing the use of desalination to potential clients.

The following chapter explains why Zinkwazi is of strategic importance to Umgeni Water and details the reasons why Zinkwazi is a suitable town for investigating desalination as a viable potable water supply alternative.

CHAPTER 5

5 CASE STUDY – ZINKWAZI

5.1 Introduction

Zinkwazi is a coastal town situated on the KwaZulu-Natal north coast approximately 30 km north of Stanger. The town has a population of 1000 according to the 1996 Census data, but this increases significantly during holiday periods. Scattered rural communities also live adjacent to the town mostly on privately owned farmland. Zinkwazi falls within the jurisdiction of the Ilembe District Municipality (IDM) and its water supply is the responsibility of this Municipality as defined by the Water Services Act (108 of 1997). The town's growth has been limited by its existing water supply (Ilembe District Municipality, 2002, p.55).

5.2 Existing water supply

The town is solely dependent on groundwater for its water supply and currently has five production boreholes pumping to two distribution reservoirs. Three of these boreholes are providing good yields, while the other two a providing marginal yields. There is no water treatment plant and only chlorine is added to the water to disinfect it.

Water quality does not comply with SABS 241 drinking water standards with both Nitrates and Phosphates exceeding recommending limits. Prolonged exposure to Nitrates is particularly dangerous to newborn babies who are at risk of developing "blue baby syndrome".

Existing infrastructure is also in need of attention with the older boreholes and pipelines requiring refurbishment or replacement.

The most pressing problem, however, is the limited water supply available from the existing groundwater resources, which cannot meet seasonal demands. The sustainable yield available from the boreholes system is 650 kl/day (Van Niekerk, 2004).

5.3 Demands

The current demand of 850 kl/day cannot be met by the existing yield of the system; over and above, which during holiday seasons the demand is estimated as increasing to approximately 1000 kl/day (Van Niekerk, 2004). As this cannot be met by the existing supply, restrictions are normally put in place on certain water usages e.g. garden watering. To make matters worse a new housing development, called Panorama Park, is currently being constructed, which will increase the demand for water.

5.4 Implications

Despite current developments such as Panorama Park, the limited water supply has curtailed development in Zinkwazi and various proposed developments have been forestalled as a result. Zinkwazi forms part of an important development axis on the North Coast running between the neighbouring town of Darnall. The lack of an adequate water supply has serious implications for the regions micro economic development. New townships are being built in Darnall and with limited job opportunities in Darnall the tourism industry, predominantly centred in Zinkwazi, represents the regions best opportunity for job creation. The continuing restrictions and lack of development is also curtailing the Municipalities exiting and potential revenue from water sales. This in turn affects the Municipalities financial viability and inhibits its ability to provide services to the unserved as is its mandate as a Water Services Authority (WSA).

5.5 The case for Umgeni Water's Intervention

Umgeni Water is the regional bulk water supplier for the lower North Coast (NC) region (**Figure 3** NC Supply Region), and in particular for the Ilembe District Municipality (IDM), in which the town of Zinkwazi lies. Although the IDM has its own water supply sources such as the Stanger waterworks a large portion of its supply is from Umgeni Water operated pipelines.

The IDM is thus in terms of sales and geographical potion a strategically important customer for the organisation. It is Umgeni Water's strategy to grow the organisation's customer base and to assist municipalities in supplying water services. Zinkwazi is a town with a water supply problem. Umgeni Water has conducted a number of water supply investigations on behalf of the Municipality in the past. The opportunity therefore exists for Umgeni Water to assist the IDM in resolving the town's water supply problems.

Concomitant to resolving Zinkwazi's water supply problems, assisting the IDM makes strategic sense for Umgeni Water as it offers the following opportunities. Success for Umgeni Water at Zinkwazi means better opportunities for meeting other water supply problems within the IDM. Success in desalination means a track record for Umgeni Water in a growing industry and the opportunity to diversify further into this field, which is increasingly becoming important in many African and other countries throughout the world.

Umgeni Water is strategically placed to assist at Zinkwazi because:

- Umgeni Water has a geographical presence in the area
- Umgeni Water has worked previously in the area and undertaken feasibility studies into the water supply situation at Zinkwazi and the surrounding towns and communities. This information is thus available free of charge.
- Umgeni Water has a dedicated and unique Process Evaluation Facility where pilot plants can be manufactured and tested.
- Umgeni Water has experienced Process Services staff to design, implement and manage a desalination plant.
- Umgeni Water can assist the IDM in obtaining funding for the project if this is required.

5.6 Conclusion

Zinkwazi has a water supply problem, both from a quality and quantity perspective. The existing borehole supply is old and cannot meet the current and future demands of the town. This has lead to water restrictions and has retarded economic development and growth. The town also has no water treatment plant and the water quality does not meet potable water quality standards for some determinants.

Umgeni Water as a regional bulk water service provider to the Ilembe District Municipality, within which Zinkwazi falls, has a strategic interest in resolving the water supply problems at Zinkwazi. This is strategically important to Umgeni Water for a number of reasons including:

- Goodwill: Zinkwazi is a small community that in regional terms does not use a lot of water. Umgeni Water is therefore not going to make a lot of money from water sales if the organisation takes over the water supply to the town. Resolving the Municipality's water supply problems may, however, be seen as an appropriate gesture of good faith and relationship building. This may in turn open the door to larger more lucrative bulk water supply agreements.
- Experience: Umgeni Water needs experience in desalination if it is going to make an impact in the desalination market. Owning or operating a desalination plant at Zinkwazi will provide the required stepping stone into the market.

In the next chapter desalination and a number of other water supply alternatives are investigated as a means of augmenting or replacing the existing borehole water supply to Zinkwazi. Pre-feasibility investigations were undertaken and costs of the various options provided for alter use in an economic analysis.

CHAPTER 6

6 WATER SUPPLY ALTERNATIVES

As stated in the previous section, the North Coast area and the IDM has been the subject of a number of water supply studies. In water supply planning the goal is to balance water supply with water demand in the most economical way. Water supply planning can be looked at from the long, medium and short-term perspectives. The reason for this is that water supply infrastructure such as dams and pipelines can be extremely capital intensive. A problem can arise when large water supply assets are not fully utilized at implementation because the demand is insufficient and has to grow. This results in the infrastructure being amortized over long periods of up to 30 years, resulting in funding for such projects being difficult to obtain.

Wherever possible planners therefore attempt to reduce this scenario by providing water supply solutions over the short to medium term, until demand justifies the construction of large, expensive water supply infrastructure.

Various water supply options have thus been proposed to meet the water supply needs at Zinkwazi. Water supply investigations within the Ilembe District Municipality previously undertaken by Umgeni Water were studied to determine their applicability in meeting the water needs of Zinkwazi. The most relevant of these investigations are discussed below. An economic analysis will then be undertaken on those water supply options that have potential to meet the water needs of Zinkwazi.

All the information taken from previous investigations and the work done for this study is at a pre-feasibility level. Pre-feasibility level investigations involve only preliminary design and costing. This level of study is utilized to differentiate between, by means of an economic analysis, the feasibility of various water supply options. The more economically feasible options are then taken to a high level of investigation (Detailed Feasibility) and the other options discarded. Detailed feasibility involves detailed design and more accurate costing. This information is then used in a financial analysis to determine the financial viability of a particular option. For the purposes of this dissertation only pre-feasibility level investigations will be done.

6.1 Mvoti Development

This scheme is a regional scheme planned by Umgeni Water to supply the whole of the North Coast region up to and including Zinkwazi (Refer to **Figure 3, Annexure D**). The estimated cost of the entire infrastructure required for this development is as follows (Stimela Bosch & Associates, 2004, p.55).

Isithundu Dam	R220 million
Abstraction Works	R 65 million
Fawsley Park Waterworks &	
Connecting Infrastructure	R165 million
Total	**R450 million**

This alternative is orders of magnitude more expensive than other water supply alternatives. Moreover, the water demand required for this scheme to be economically feasible are projected to occur only in 2017. Zinkwazi clearly cannot wait this long and therefore the Mvoti development is seen as long-term water supply solution for the area, including Zinkwazi. For this reason this alternative was not considered further in the economic evaluation undertaken in this study.

6.2 Groundwater

Augmenting the existing borehole supply in Zinkwazi from groundwater is not considered a viable long-term option of supplying future demands. This alternative will therefore not be investigated further. The main reasons for this are listed below: -

- The existing groundwater resources are fully utilized. Drilling more boreholes into these aquifers could lead to aquifer dewatering and potentially to salt-water intrusion. If this occurred the aquifer could be permanently damaged.
- Groundwater drilling programmes conducted around Zinkwazi have indicated low groundwater potential (Geomeasure Services, 1997a, p.12).
- The most recently successful groundwater-drilling programme took place in the coastal dunes south of Zinkwazi (Geomeasure Services, 1997b, p.6). The combined yields of boreholes drilled were 216 kl/day. The water obtained from these boreholes was of such poor quality that it couldn't be incorporated into the existing system without treatment.

All the water quality samples were classified as Class 3 (unsuitable for human consumption without treatment) sources with high concentrations of calcium, iron, manganese and sulphate. The combined yield obtained from this source is also suitable for only increasing the assurance of supply of the existing resources and is not sufficient to cater for new developments. A new water supply source would thus have to be found as demands increased.

6.2 North Coast Supply System Transfer

This alternative proposes the transfer of potable water from the town of Stanger via the construction of a gravity fed bulk water pipeline to Zinkwazi (Refer to **Figure 3, Annexure D**). The pipeline would be sized to cater for all demands between Stanger and Zinkwazi thereby catering for the demands of Darnall and rural communities. The bulk water infrastructure at Stanger does, however, not have sufficient storage capacity to meet the increased demands and would therefore also have to be upgraded (Umgeni Water, 2002, p.26).

Based on sub-regional demands projected at a growth rate of 1.5%, 1 Ml/day can be supplied to Zinkwazi via a 150 mm diameter pipeline. Detailed costs of the infrastructure required for this alternative are given in **Annexure E**.

6.3 Mandini / Tugela Transfer

This alternative proposes the transfer of potable water from the town of Mandini via the construction of a bulk water pipeline to Zinkwazi (Refer to **Figure 3, Annexure D**).

Sappi abstracts raw water from the North bank of the Tugela River. At the abstraction works the water is clarified and flocculated at the Sappi treatment plant. The flocculated water is then pumped to the 1.5 Ml Tugela filtration plant located adjacent to the abstraction works and the Sappi holding tank located in Mandini.

It has been identified that the existing 1.5 Ml/day Tugela Filtration Plant can be upgraded to 3.0 Ml/day to augment the potable water supply to Zinkwazi (Umgeni Water, 2002, p.27). The existing bulk infrastructure from the Tugela Filtration Plant has limited capacity and a new rising main will have to be laid to supply Zinkwazi. It has been assumed that 1.5 Ml/day of the upgraded 3.0 Ml/day Filtration Plant would be supplied to Zinkwazi.

6.4 Desalination

The fourth and final water supply alternative proposed for Zinkwazi is desalination. A Seawater Reverse Osmosis (SWRO) desalination plant capable of producing 1.5 Ml/day of potable water is proposed, using a seawater abstraction system from beach wells. The estimated costs of the infrastructure required for this option are presented in **Annexure E**. The feasibility of using desalination to meet the water supply needs of Zinkwazi is given in Chapter 7. Consulting Civil Engineers Stimela Bosch & Associates (SBA) (2004, p.57) indicated that they felt the use of a desalination pant at Zinkwazi appeared viable and they recommended a detailed feasibility investigation be undertaken.

6.5 Conclusion

Of the water supply options investigated for Zinkwazi, only the supply from Mandini / Tugela and Stanger were worth investigating further, along with desalination. The regional supply from Mvoti proved to be too expensive and the timing of this initiative does not match the immediate requirements of Zinkwazi. Groundwater potential was shown to be inadequate to meet future demands and was therefore not considered.

The feasibility and cost of these alternatives, with the exception of desalination has been established in previous studies. A breakdown of the costs of implementing these schemes is given in **Annexure E**. The planning involved and the design of these schemes is not of relevance to the dissertation and information about these schemes is available from the reports referenced.

Of particular relevance to the dissertation is the implementation of a desalination scheme, as this has not been investigated before. **Chapter 7** therefore takes a detailed look at the feasibility of desalination at Zinkwazi.

CHAPTER 7

7 POTENTIAL FOR SEAWATER DESALINATION FOR ZINKWAZI TOWN

Desalination is not suitable for every location even if the site is near the coast. The town of Zinkwazi has some particular attributes that make it potentially suitable for the construction of a desalination plant. These attributes are not confined to location alone and may include, water demand, availability of alternative supply options, coastal conditions and seawater quality, power availability and environmental issues. In this chapter these and other issues are discussed in relation to how they affect the suitability of Zinkwazi as a site for a desalination plant. The discussion goes as far as to recommend a certain desalination technology and the reasons behind this recommendation are given.

7.1 Recommended Technology

Membrane technology is proposed as the most appropriate desalination technology for Zinkwazi. The advantages of membrane technology over other desalination processes were introduced in **Chapter 3,** however, in the context of Zinkwazi other advantages are discussed below. The preferred desalination technology for Zinkwazi is also dependent on the available energy sources.

At the time of this study, electricity from the national grid was the only available energy source, resulting in the selection of membrane technology as the preferred and most economically viable technology for Zinkwazi. Membrane technology is well developed and can be regarded as a standard unit process known to perform to the required specifications (Ninham Shand, 2002a, p.21).

Some of the advantages of the membrane desalination process, adapted from Elarde and Bergman (2001, p.3), include the following: -

- Membrane treatment minimizes the required chlorine dose necessary to meet additional inactivation and residual disinfection requirements. Lower chlorine doses and contact times as a result of pathogen removal credit by membrane filtration will also reduce the production of disinfection by-products (DBPs) during finished water disinfection.

- Many utilities require a water treatment plant with a small footprint that can blend in with a surrounding community. Membrane filtration typically requires less chemical addition then conventional processes, which results in smaller bulk chemical storage tanks and feed facilities. Membrane filtration does not require the large structures associated with clarifiers and media filters. This is especially true of a holiday resort like Zinkwazi, where obtrusive structures near the sea would be unwelcome.
- Membrane filtration plants are easier to operate and monitor and require less supervision than conventional plants.
- Operation and Maintenance (O&M) cost: Labour and general maintenance are fixed O&M costs, which will remain relatively constant independent of membrane plant size.

SWRO technology supplied by GrahamTek, a South African desalination plant manufacturer, is recommended for use in Zinkwazi. The technology was chosen as it represents a patented new desalination technology that does not require pre-treatment chemicals. It also is the only operational desalination technology being used for municipal water supply in SA, which makes it ideal as it has an established operational track record. As part of the decision to use GrahamTek desalination a site visit to a GrahamTek desalination plant at Kenton-on-Sea in the Eastern Cape was undertaken. A detailed explanation of the technology and its applicability to the Zinkwazi case study are provided in the next sections. The experiences of the Kenton-on-Sea plant and how these provide insight into possible implementation and operation considerations for desalination at Zinkwazi are also elaborated on.

The optimisation of a desalination plant can only be done if there is sufficient information about seawater quality, the location of abstraction site and the required product water quality. Obtaining such information is beyond the scope of this report and would normally be provided by the various technology suppliers with a formal tender. Thus the information compiled in this report needs to be considered as the best available information obtainable without calling for formal tenders, but is sufficient for this pre-feasibility level of study.

7.2 Desalination Manufacturer (GrahamTek)

GrahamTek's innovative reverse osmosis plants use patented membrane water treatment techniques. These techniques have significantly refined and improved conventional reverse osmosis technology, eliminating the traditional membrane fouling, high energy consumption barriers-to-entry experienced in existing membrane separation processes (Water Sewage and Effluent, 1998, p.6).

The plant is modular in design and can be linked together providing plants of varying capacities. The plant footprint is about 58% smaller than comparative competitive plants processing similar capacities and therefore is ideal for coastal resorts where space is often at a premium.

The GrahamTek RO technologies incorporate two important innovations, a unique flow distributor and an 'in-service' membrane defouling device which allow a different approach to membrane systems design (Water Sewage & Effluent, 1998, p.6).

7.2.1 Flow Distributor

The Flow Distributor is placed directly in front of the membrane elements, directing more flow towards the centre of the spirally wound membrane, where lower velocity is traditionally found.

In addition, the Flow Distributor also expels gasses from the feed water while under pressure, creating gaseous microspheres, which enhance mixing, through disruption, within the boundary layer. Consequently, the microspheres act as a scouring agent, disrupting ions at the concentration polarisation layer, carrying away ions from the membrane surface more rapidly. The result is a lower osmotic pressure at the membrane surface, leading to greater net driving force (Water Sewage & Effluent, 1998, p.7).

7.2.2 Magnetic defouling device

The electromagnetic device, which surrounds the membranes, affects both ionic and organic species in the feedwater, deterring both precipitation and membrane fouling thereby effectively prolonging the life of the membranes.

7.2.3 Advantages of GrahamTek SWRO Technology

Performance data captured over a five-year period from a seawater installation was interpreted and evaluated by various independent suppliers in the membrane separations industry. Their analysis and findings verify the higher performance, energy efficiency non-fouling properties of GrahamTek's innovative technologies (Water Sewage & Effluent, 1998, p.7). Some of the advantages of GrahamTek in comparison to other competitor's products available on the market are summarized in **Annexure F.**

7.2.4 Other Considerations

In locations where seawater can be supplied from beach wells, a simple design system can be employed to avoid the need for chemicals injection as part of the pre-treatment of the raw water (Glueckstern, 1999, p.134).

7.3. Site Location

Suitable sites in and around Zinkwazi need to be identified based on suitable sites for seawater extraction, the water demand for the area, the existence of suitable bulk infrastructure, socio-economic considerations, and potential environmental impacts.

Beach wells and other non-surface seawater intakes have advantages over surface seawater intake systems, because of the filtering capability of the beach sands. The beach well system has been successfully used with minimum pre-treatment for SWRO plants in several locations around the world (Schwarz, 2000, p.10).

7.3.1 Potential sites for desalination plant

The position of the desalination plant is strongly dependent on the most suitable position of the beach wells at Zinkwazi and is vitally important for the following reasons:

- The closer to the plant the wells can be the greater the reduction in capital expenditure and operating costs. Pump size, pipeline length and pumping head (electricity costs) can be reduced in most cases.
- The beach wells need to be sited in the most suitable position to optimise the yield from the wells. The sitting of these boreholes, however, requires approval from the Department of Water Affairs & Forestry (DWAF) and the Department of Agriculture and Environmental Affairs (DAEA) to ensure that no seawater ingress into fresh water aquifers occurs.

Potential sites were therefore sought in the vicinity of Zinkwazi, i.e. south and north of the town. Two potential sites were identified, namely:

Site A, which is situated at the mouth of the Zinkwazi river on the south bank; and
Site B, which is situated south of the town in an open area of land close to the beach.

Figure 4 & 5 in **Annexure G** show the location of the above two sites relative to the existing bulk infrastructure.

A critical factor in the choice of sites for the beach wells will be the porosity and transmissivity of the sands at the two sites. These parameters can be established through site investigations whereby sand samples are obtained from auguring and sent to a laboratory for a sieve analysis. Such materials testing would be complemented by in-situ pump (drawdown) tests.

The transmissivity of the sands will be vitally important in establishing the amount of water that can be extracted per borehole. Thus the greater the transmissivity the fewer production boreholes need to be drilled and equipped thus reducing the capital and operating cost.

A potential disadvantage of Site A may be the possibility of clay sediments deposited by the river being interlayered with the sands, which could result in retardance of flow. The beach sands at Site B would not have this problem as they have been deposited solely by wave action.

7.3.2 Socio-economic considerations

The major concern about the construction of a desalination plant at Zinkwazi will be public opinion on the aesthetics of the intake structures, pump station and plant and the effect on the integrity and visitor experience at Zinkwazi.

Table 7 below compares various socio-economic considerations for both potential sites. These considerations are those of the author and are not exhaustive.

Table 7: Comparison of Socio-Economic Considerations

Consideration	Site A - Zinkwazi River	Site B - South Beach
Construction activities	Construction activity has potential to be disruptive as access roads are through residential areas	Possibility of access road construction to avoid residential areas, otherwise similar problems to Site A.
Noise generated by desalination plant	Close proximity to residential housing may be problematic in terms of noise pollution.	Fairly well removed from neighbouring houses, noise unlikely to be a problem.
Aesthetics	Site not visible from residential areas but will be an eyesore for river users unless mitigation measures can be taken.	Fairly obtrusive site with little or no protection from surrounding landscape and vegetation

Proper planning, together with a comprehensive public participation process could mitigate the above socio-economic considerations.

7.4 Plant Configuration

A SWRO plant comprises typically of five sections. These are: (1) seawater intake, (2) pre-treatment, (3) desalination section, which contains high-pressure pumps and membranes, (4) post treatment and (5) brine disposal section (Schwarz, 2000, p.22). A typical seawater desalination plant flow chart is presented in **Figure 6** below.

7.4.1 Intake

The feed water that is supplied in a non-surface system from underground abstraction facilities such as pumping wells is pre-filtered naturally in the small pores of the underground formation and in the gravel and sand pack that surrounds the borehole. The reduced biological activity, results in saving in investment in pre-treatment plant and operation costs of chemicals, and minimizes the potential risk of bio-fouling in the whole system. The lower bio-fouling activity may eliminate the need of pre-chlorination, or using small quantities of chlorine, for disinfection. This benign situation does not exist in pumping surface seawater.

The usage of a beach well seawater intake system reduces the capital costs of the intake and pre-treatment systems, and adds also to longer lifetime of the membranes, lower operation expenses and manpower, and reduces the amount of consumed chemicals. The saving in pre-treatment filtration equipment can save also the total area needed for the plant, thus saving in total investment (Schwarz, 2000, p.51).

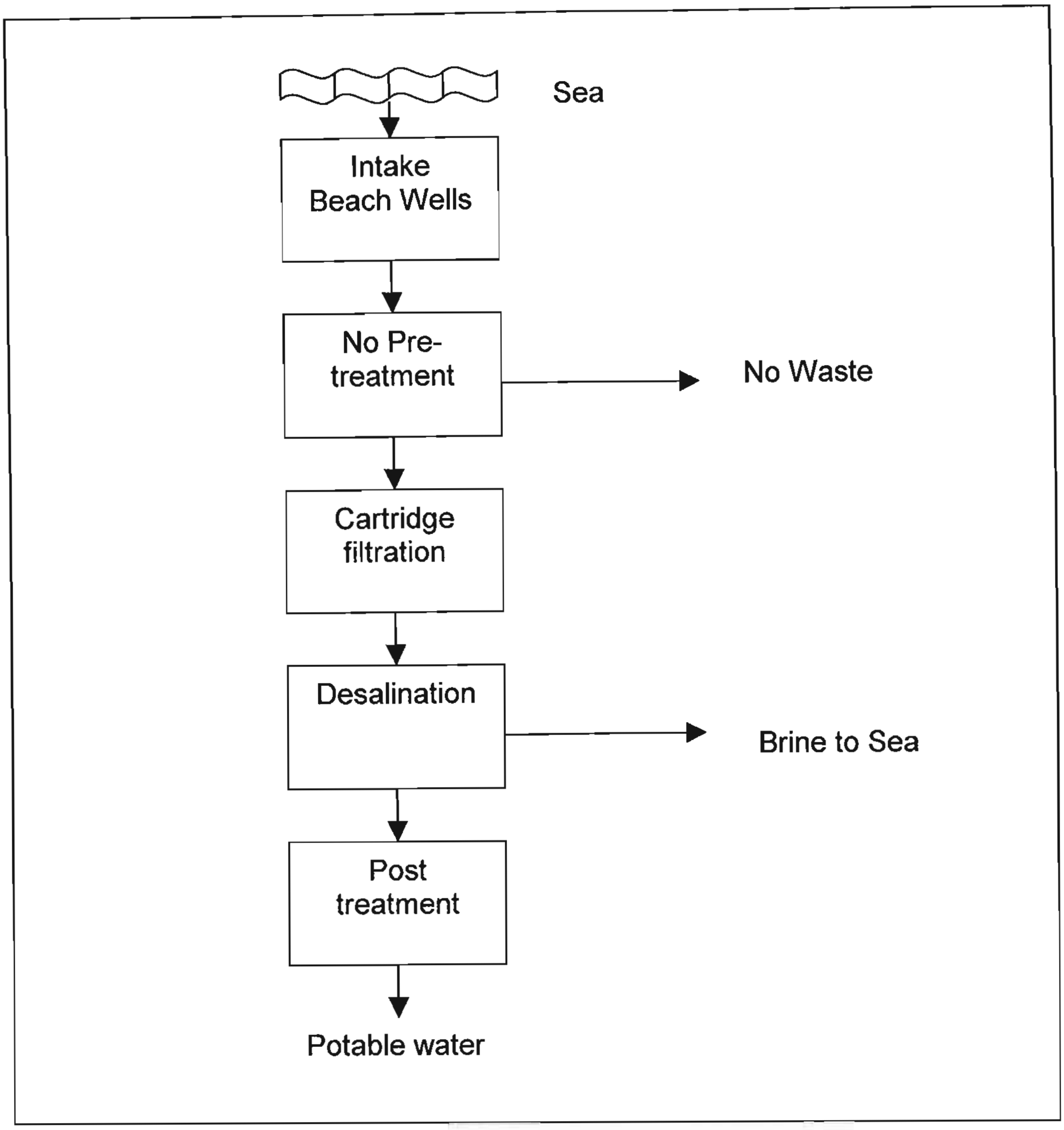

Figure 6: Typical seawater desalination plant configuration.

Source: Ninham Shand, (2002b, p.3)

7.4.2 Pre-treatment

By using a beach well system to abstract seawater there will be no need for pre-treatment requiring the addition of chemicals as mentioned above. Some form of pre-filtration to remove suspended solids will however be necessary. The GrahamTek desalination plant is equipped with cartridge filters capable of reducing suspended solids from 2 400 NTU's to less than 1 NTU in a single pass.

7.4.3 Desalination Section

7.4.3.1 Membrane type

Given a feed water salinity of 35 000 mg/l TDS the GrahamTek SWRO membranes will yield recovery rates of approximately 45 % (Smith, 2003). A redundancy of ± 10% should be allowed for in the design for cleaning in place (CIP) and maintenance requirements (Ninham Shand, 2002a, p.32).

As there is always a possibility that operational complications can arise, Glueckstern (1999, p.136) goes even further and recommends that provision be made for increased desalinated water storage capacity, as well as plant over-capacity. Twenty to 50 % plant over-capacity and a storage capacity of 3-6 times the daily water consumption should be considered for small and medium-size desalination plants.

Apart from electricity costs, membrane replacement accounts for the biggest operational expense in reverse osmosis plants. However, seawater desalination membrane materials have improved over the last decade, and it is now standard to guarantee membrane life for five years subject to appropriate pre-treatment and plant operation (Ninham Shand, 2002a, p.34).

The GrahamTek membranes used at Albany Coast Water Board (ACWB) have not been replaced since start-up; over five years ago and only recently were removed temporarily for cleaning. The CEO of ACWB attributes this to good operation and maintenance, people who care and the fact that chemicals are not used in pre-treatment.

Modular

One of the attractive features of membranes is that the systems are built in modular sections (Furukawa, 1999, p.260). Thus, one may start with one module and can add additional modules, as the need requires. In this manner multiple modules can be constructed identically, reducing the requirement for spare parts redundancy (Refer to Reference Plant Site Visit **Annexure C**).

7.4.3.3 Energy recovery

Particularly for seawater, energy can be recovered from the brine, which is still at high pressure. Simple Pelton wheel devices, reverse running turbines or other more innovative devices capture 50 to 90% of the energy remaining in the brine (Furukawa, 1999, p.261). The recovered energy is then transferred to the feed pump, either through direct shaft power transfer or hydraulically boosting the feedwater (Refer to Reference Plant Site Visit **Annexure C**).

7.4.4 Post-treatment

The product water produced from desalination normally requires some form of post-treatment to bring it up to drinking water standards. Some form of pH correction is normally required to passivate the water to prevent corrosion of piping in the distribution system. This can be achieved by elevating the pH, by the addition of chemicals such as lime and sodium hydroxide. A small residual of chlorine is also added, to prevent regrowth of organisms in the distribution system (Furukawa, 1999, p.261).

Adjusting the pH, however, is not required with the GrahamTek system. The quality of the product water falls within the recommended limits of SABS 241, without any chemical treatment.

7.4.5 Brine disposal

With environmental consciousness prevalent throughout the world, the proper discharge of brine is essential. Fortunately because the GrahamTek system uses no chemicals, brine disposal is not an environmental threat. Education of the public in this regard is, however, a priority.

Even though there are no chemicals released to the environment by the GrahamTek system misconceptions may occur as has been experienced by the ACWB. The ACWB currently discharges a small volume of brine (480 kl/day), which is essentially concentrated seawater, into the estuary, which is also seawater and orders of magnitude greater in volume (Refer to Reference Plant Site Visit **Annexure C**). The mere fact that a waterworks outlet is visible to the public and discharges into a recreational area has raised complaints with some local residents. Despite assurances to residents of the total lack of toxicity of the discharge, DWAF has asked the ACWB to relay the discharge pipeline and to discharge onto the beach in a less visible area.

The situation highlights the sensitivity of environmental conscious communities and ratepayers and any Desalination development in Zinkwazi will have to be sensitive to environmental concerns raised by stakeholders.

7.5 Environmental Considerations

7.5.1 Indirect Costs and Environmental Impacts

The major environmental impacts to be considered with respect to SWRO desalination plants with well intakes are impacts on the inland fresh groundwater systems.

Two main impacts on the inland groundwater system are expected to be faced if pumping is maintained, inducing flows from the fresh groundwater body: (a) lowering groundwater tables within the usable inland fresh aquifer sections, and (b) loss of fresh groundwater by induced flow into seawater sections of the aquifer.

The (a) and (b) above are governed by: the distance of the abstraction site from the coast line, the radius of influence (depending on the aquifer's Transmissivity and Storativity), the discharge rate, intake depth, and the size and capacities of the inland aquifer.

Quantification of these indirect costs is by means of estimating losses of water to the inland water supply system and charging desalination costs with the production of additional desalinated water to cover the deficit. However these indirect costs are nil if the inland water is not used (Schwarz, 2000, p.54).

This is the currently the case at Zinkwazi where the groundwater aquifer south of the town is not being utilized. Previous investigations (Geomeasure Services, 1997b, p.5) have also indicated that the groundwater is of such poor quality that extensive treatment would be required to make it acceptable for drinking water. It is thus unlikely that it would be used for this purpose; therefore any objections as to the possible affects of seawater intrusion may be negated.

It is, however, vitally important that before any decision on where to site the beach wells is taken that a DAEA approved Environmental Impact Assessment (EIA) is undertaken. Any EIA will not only determine the environmental impact of seawater abstraction on fresh groundwater resources, but will also involve extensive public participation in decision-making. The experiences of the ACWB indicate that if a desalination project is to be implemented successfully it is essential that stakeholders are educated and informed about technical and environmental matters so that they can make better-informed decisions (Ball, 2003).

The construction of a desalination plant at Zinkwazi benefits the environment as it reduces the abstraction of groundwater and negates the need for the construction of a dam or pipeline to supply water to Zinkwazi. Dams can have negative environmental impacts.

7.5.2 EIA

The drilling of a well field for extraction purposes will require a water license. In order to obtain a licence the Department of Water Affairs & Forestry will require supporting documentation that has considered the potential environmental impacts of the proposed extraction.

In addition, the proposed extraction also falls under Section 22 of the Environment Conservation Act (73 of 1989) as a listed activity and therefore an environmental impact assessment process culminating in a Record of Decision from the KwaZulu-Natal DAEA will be required. A record of decision is obtainable by following the EIA process outlined in the EIA regulations.

Undertaking the EIA has the following overall benefits:

- Protects the environment
- Minimises planning approval timescales
- Minimises time for arranging funding
- Meets the environmental policy of sponsors and contractors
- Minimises overall construction timescales

Paramjit Mahi (2001, p.6) believes these benefits can be achieved if the developer recognises that the project will be environmentally ‘driven’ from site inspection to decommissioning and as such develop a project strategy with this in mind from day one. Some environmental issues that need to be addressed in this project strategy are:

- Site identification / Site Selection – Site identification is often based on engineering factors to minimise cost of infrastructure whereas site selection should be based on environmental and engineering factors to ensure timely award of consents and licences. Greater weight should be given to engineering factors over environmental factors during site identification (to arrive at a number of alternative sites) and the order should be reversed during site selection
- Public Relations – Public relations is an important issue in 'stakeholder concept'. In such cases the developer is encouraged to provide an analysis of alternatives to demonstrate to the public why the selected site and technology are ideally suited at the selected location.
- Planning Approvals (design, construction and operation) – It is important to obtain all national and funding agency approvals. An early review of consents and licences required is recommended.
- Environmental Standards / Plant Performance – The plant should be designed to environmental standards set by national government and funding agencies.
- Environmental Management Plans – These are required for the construction and operational phases of the project. These plans should also include the setting up of community liaison groups to allow public feedback.

7.5.3 Legislative Considerations

The national scarcity of water resources dictates water users and providers use water sustainably. This is recognised in recent water legislation, namely the National Water Act (36 of 1998) and the Water Services Act (108 of 1997). It is considered that the use of desalinated seawater meets the intent of this legislation in that it alleviates some of the stress on the traditional surface and groundwater resources.

Licences would need to be obtained from DWAF for abstracting seawater and from the Department of Agriculture and Environmental Affairs (DAEA) to discharge the brine. However, it is unclear in the legislation which licences are required, and this should be clarified with DWAF and DAEA. The desalination plant and associated infrastructure would require authorisation from the Department of Environmental and Cultural Affairs and Sport (DECAS), as well as the South African Heritage Resources Agency.

7.6 Water Quality

Typically Indian Ocean coastal water usually contains plankton and carbohydrate exudates from kelp and other seawater vegetation. These constituents and suspended silt, oily emulsions, etc. will need to be removed to meet the required feed water quality for the reverse osmosis process. In particular, a silt density index (SDI) of less than three is obligatory (Ninham Shand, 2002a, p.12).

It is expected that a product water quality of 400 to 600 mg/l TDS will be produced from the SWRO desalination plant based on results achieved at ACWB and specifications provided by GrahamTek. These TDS concentraions fall within the limits of SABS 241 drinking water specification. The salinity can, however, be further reduced through blending with the existing Zinkwazi potable groundwater source, if required. The location for blending will have to be carefully selected to provide adequate dilution. It may be necessary to transfer the desalinated water to the Zinkwazi Reservoir to obtain the necessary dilution.

7.7 Plant Sizing

The selected plant size at Zinkwazi is linked to the current and projected demands, as the yield from seawater is unlimited. One of the advantages of desalination, especially reverse osmosis, is the option of increasing the plant size incrementally as the demand increases.

It is estimated that Zinkwazi demand will increase by from the current demand of 1 Ml/day to 1.5 Ml/d over the next 20 years at estimated growth rate at 1.5%/annum. A desalination plant of 1 Ml/day would thus be sufficient to meet the current demand and desalination units of 0.5 Ml/d may be added on an incremental basis as demand increases. Alternatively a 1.5Ml/day plant can be installed immediately.

7.8 Operation & Maintenance Considerations

For remote locations, the importance of reliability of desalinated water supply cannot be overemphasized (Glueckstern, 1999, p.130). Both technological and human factors must function at their upper limit to achieve this goal. The human factors to be considered are initial and continuous training of operators and maintenance staff to a level adequate to the applied technology (Glueckstern, 1999, p.130). Well-trained operators are essential in ensuring the sustainability of the plant and preventing any damage to the plant and the membranes.

Maintenance of the plant is efficient as the modular design allows for individual shut down of each reverse osmosis vessel. The rest of the plant can continue to operate during maintenance so no loss of productivity occurs. Bask washing of the membranes is automatic and is controlled by programmable logic controllers (PLC).

Extensive sampling is not required at the GrahamTek SWRO plant as the measurement of EC and pH are the only water quality constituents that require measurement for operational purposes (Ball, 2003).

Due to high pressures, leaks and holes sometimes occur during normal operation of a desalination plant. Repairing leaks as soon as possible avoids excessive downtime and reduces the threat of a major burst, which is also a safety concern (Ball, 2003).

7.9 Materials

The selection of proper corrosion-resistant material for high-pressure pumps and piping is of great importance (Glueckstern, 1999, p.136). It is therefore recommended that all pipework upstream of the product water reservoirs (i.e. pipeline from sea intake to desalination plant) should be manufactured from GRP, HDPE or MPVC. These pipe materials are resistant to corrosion by seawater (Ninham Shand, 2002a, p.34).

Due to the high pressures (approximately 60 bar) most pipes and fittings in the desalination section of the plant should be made of 316 grade stainless steel.

Any economically feasible pipe material with adequate corrosion resistance could be used downstream of the product water reservoir to convey the treated water to the service reservoirs (Ninham Shand, 2002a, p.34).

Stainless steel pumps and impellers are also required for corrosion protection.

7.10 Human Resources and Training

The ACWB operates with a staff compliment of six i.e. two labourers, two technicians/operators, a CEO and a secretary. Two operators working 8 hr shifts and one extra assistant during peak season man the plant.

The proposed Zinkwazi desalination plant is the same capacity as the ACWB plant and the human resource requirements will therefore be similar. The Ilembe District Municipality has taken over the operation of the water supply system at Zinkwazi and has existing staff responsible for it's functioning.

It is likely that training of existing staff with perhaps the employment of another operator is all that will be required in terms of human resources for the operation of the desalination plant. It should, however, be noted that the CEO of the ACWB stressed the critical importance of obtaining the right people to operate the plant.

7.11 Capital & Operating Costs

According to Glueckstern (1999, p.139) recent studies have shown that the cost difference between desalinated water from a medium-size SWRO plant fed with high quality seawater from beach wells and water from a plant fed by an open surface intake is in the range of 1.5 – 2.0 in favour of beach wells.

7.12 Conclusion

Membrane technology, specifically RO has a number of advantages over other desalination technologies. Of particular relevance to Zinkwazi is the fact that RO plants have a small footprint that can blend in with the surrounding community, which is important for a holiday resort town. Membrane filtration plants are easier to operate and monitor and require less supervision than conventional plants. This would be advantageous to the Municipality, reducing labour and time costs.

The use of locally manufactured GrahamTek membrane technology is recommended as it has a unique patented technology that does not require the use of pre-treatment chemicals, thus reducing operating costs. A site visit to a desalination plant at Albany Coast Water Board helped establish the credibility and operational track record of this technology were it has been used successfully for the past five years.

Beach-well abstractions are proposed for Zinkwazi as they are cheaper to construct than surface seawater abstractions and they minimise pre-treatment costs through the filtration properties of the beach deposits.

Two potential sites for the beach wells have been identified, one south of the town and the other north of the town on the banks of the Zinkwazi River. Both have their advantages and disadvantages, but further investigations, including an analysis of the porosity of the sands will have to be undertaken before any decision can be made.

Environmental considerations are vitally important when proposing construction of a desalination plant and all stakeholders must be involved prior to implementation of a desalination project. Issues or relevance include brine disposal and seawater intrusion into groundwater resources when using beach wells. Appropriate EIA's approved by the DAEA are essential.

Those factors that make the use of desalination technology applicable to use at Zinkwazi have been considered in this chapter. Desalination as a means of supplying water to Zinkwazi is considered a viable option. In the next chapter desalination along with surface water supply options are analysed from an economic standpoint to determine which is the most economically viable alternative.

CHAPTER 8

8 ECONOMIC ANALYSIS

The possible development options to supply water to Zinkwazi are described in the previous sections. The purpose of the economic analysis is to assess the cost and benefit of each development option so that the most economically viable alternative can be identified. A pre-feasibility level economic comparative analysis was undertaken for the three alternative supply options. Details of the analysis may be found in **Annexure H**.

8.1 Capital Cost Assumptions

The capital costs were determined based on the following assumptions:

- Pumpstations have been sized and costed at the maximum demand of 1.5 Ml/day.
- Capital costs have been based on recent construction projects undertaken by Umgeni, and on information from suppliers and were escalated to 2003 prices.
- Environmental professional fees (7%) have been included in the capital cost. This environmental cost should cover associated public participation and any social impact assessments
- Engineering professional fees (12%) and contingencies (10%) are also included in the overall capital cost.
- VAT is excluded.
- Base year is 2003.
- A cost for each type and size of infrastructure, i.e. reservoirs, pipelines; etc is presented in **Annexure E.**

8.2 Operating Cost Assumptions

- Annual operation and maintenance costs were estimated as a percentage of the capital cost using the following values: 0.25% of capital costs for civil components of pump stations, pipelines, reservoirs, water works and 4.0% for all mechanical and electrical components.
- Additional allowances for pump stations and the desalination plant have been included. For pump stations a refurbishment allowance of 15% of capital cost every 15

years was included. For the desalination plant an operation and maintenance cost of 4% of capital cost per annum has been included to account for membrane replacement cost every 5 years, over and above normal operation and maintenance costs. A figure of 4% is used, as a desalination plant is essentially mechanical and electrical infrastructure. Had the plant been considered civil infrastructure a figure of 0.25% would have been appropriate.

- Energy costs are incurred in pumping water. This cost is proportional to the demand required relative to a particular development option incremental yield. Energy costs for pump stations have been based on 24c/kWh.
- Pumpsets in this analysis operate for 14 hours per day.

8.3 Economic Evaluation Assumptions

- The NPV is taken as that sum of money, which, if invested at present, would just meet all capital, operating, and maintenance costs over the life of the project (Umgeni Water, 1998, p.21).
- All cash flows are present prices, i.e. the effect of inflation is removed from the analysis. The discount rate then is effectively the net cost of borrowed money, (i.e. the difference between the inflation and the real interest rate).
- Umgeni Water normally uses discount rates of 6%, 8% and 10% and therefore these rates were used.
- Generally the cost of the project should be considered to be redeemable over 20 years (Umgeni Water, 1998, p.22). The sensitivity analysis was conducted over periods of 20, 30 and 40 years. Components with shorter economic lives should be replaced at the end of their economic lives. For this study it was assumed that although the economic live of steel pipelines is 30 years their useful life is at least 40 years and they where therefore not replaced in the analysis. For the desalination plant the membranes were to be replaced every five years.
- Initial construction would take place over the first two years.
- Economic lives of capital works components
    - Reservoirs 30 years
    - Pipelines 30 years
    - Electrical equipment 15 years

- Mechanical equipment 15 years
- Membranes 5 years

- The residual value of all infrastructure at the end of its economic life is assumed to be zero. This is in part because in 20 to 40 years time technology and in particular desalination technology will have changed significantly making any assumption on the usefulness or value of this infrastructure moot. For the surface water infrastructure the likelihood is that the proposed pipelines from Mandini and the North Coast would be decommissioned. At this point much larger regional infrastructure such as the Mvoti View water supply system should be in operation.

8.4 Analysis Procedure

All future cash flows were reduced to their NPV. This is the sum of money which if presently invested would meet all capital, operating and maintenance costs over the life of the project. The following formulae is used to calculate the NPV (Umgeni Water, 1998, p.21):

$$\mathbf{NPV = \sum (F/(1+1)^n)}$$

Where: NPV = net present value

F = future cost/benefit

I = discount rate

N = number of years

As future discount rates are unpredictable, the NPV was calculated for a range of discount rates viz. 6%, 8% and 10%. The analysis was conducted for each scheme for 20, 30 and 40 year periods. All costs were based on the 2003 pre-feasibility prices. For the purposes of the economic comparison, the Unit Reference Value (URV) was used. That is, the URV for each discount rate was calculated by dividing the NPV of all costs by the NPV of water delivered over the life of the project. It is important to note that the URV provides a basis for evaluation which may not reflect the actual unit cost of water produced by the various development alternatives, in order to determine the most economic option for feasibility investigation.

Indirect benefits such as job creation, improvement in community health and other social benefits are not included in the analysis.

8.5 Economic Evaluation Results

The economic cashflows included the construction costs, replacement of mechanical and electrical equipment at the end of their economic lives, the annual operational costs and the annual energy costs of pumpsets. The analysis period was 30 yrs.

The results of the pre-feasibility level economic comparative analysis for the three alternative supply scenarios are tabulated below, see **Table 8.** The results of the economic analysis are also plotted to facilitate interpretation, see **Figure 7.**

Table 8: Economic Analysis Results – 30 years

Scheme	Capital Cost (R'000)	Incremental yield ('000 m^3)	Net Present Value (R'000) at Discount Rates			Unit Reference Value (cents/m^3) at Discount Rates		
			6%	8%	10%	6%	8%	10%
Desalination	8 577	548	16 516	14 611	13 209	578	642	709
Mandini / Tugela Transfer	24 028	548	25 957	25 244	24 679	908	1110	1325
NCSS to Zinkwazi	27 487	392	27 588	27 283	27 010	965	1200	1451

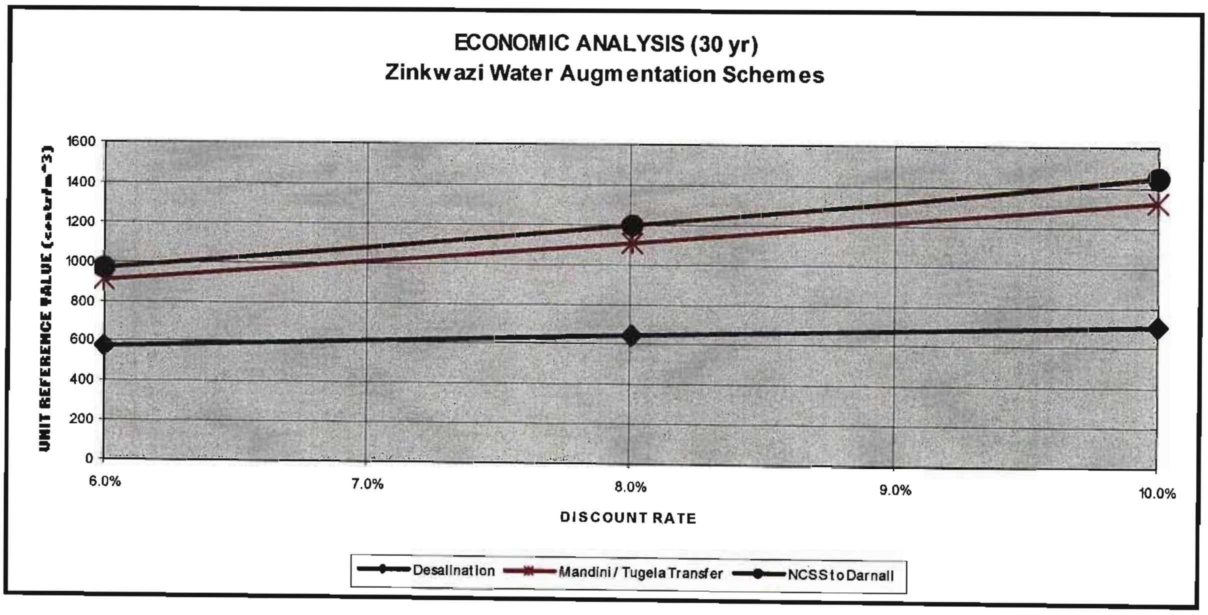

Figure 7: Economic Analysis Results (30 years)

With reference to the URV's presented in **Table 8** and **Figure 7** it clear that desalination represents the most economical means of augmenting supply to Zinkwazi. The URV's of desalination at the 6, 8 & 10% discount rates are significantly lower and therefore more economically viable compared with the other alternatives. For evaluation purposes the higher discount rate is conservatively used to account for possible difficulties in obtaining capital funding.

A sensitivity analysis was performed on the results by changing the period over which the project was evaluated to 20 and 40 years respectively. This was done to determine the affects of operation and maintenance and energy cost with time. The sensitivity of the NPV of the project is of particular interest from the perspective that the desalination plant requires the replacement of its membranes every five years. The results of the analysis are provided in **Table 9 & 10** and **Figure 8 & 9** below.

Table 9: Economic Analysis Results – 20 years

Scheme	Capital Cost (R'000)	Incremental yield ('000 m^3)	Net Present Value (R'000) at Discount Rates			Unit Reference Value (cents/m^3) at Discount Rates		
			6%	8%	10%	6%	8%	10%
Desalination	8 577	548	14 701	13 475	12 490	673	727	782
Mandini / Tugela Transfer	24 028	548	25 496	24 955	24 496	1167	1346	1535
NCSS to Zinkwazi	27 487	392	27 588	27 283	27 010	1263	1472	1692

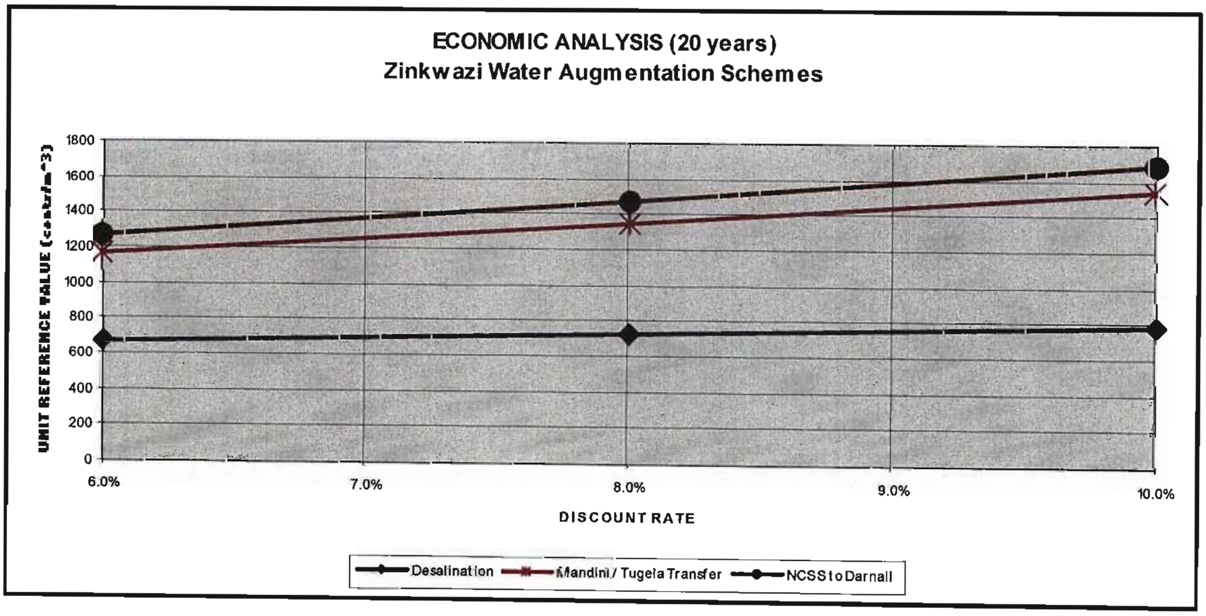

Figure 8: Economic Analysis Results (20 years)

Analysed over 20 years the URV's of all three projects are markedly higher. For example the URV for desalination at a discount rate of 6% increases from 578 cents/m^3 (30years) to 673 cents/m^3 (20 years).

Table 10: Economic Analysis Results – 40 years

Scheme	Capital Cost (R'000)	Incremental yield ('000 m^3)	Net Present Value (R'000) at Discount Rates			Unit Reference Value (cents/m^3) at Discount Rates		
			6%	8%	10%	6%	8%	10%
Desalination	8 577	548	17 716	15 235	13 538	530	603	679
Mandini / Tugela Transfer	24 028	548	26 295	25 422	24 775	787	1007	1242
NCSS to Zinkwazi	27 487	392	27 834	27 428	27 097	844	1095	1366

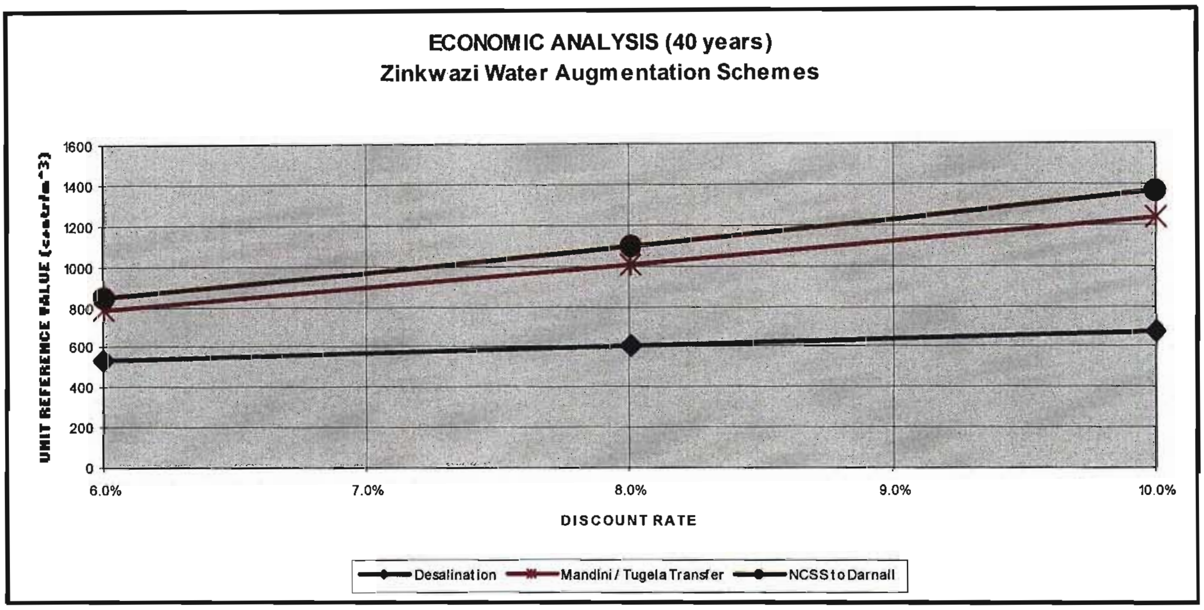

Figure 9: Economic Analysis Results (40 years)

Analysed over 40 years the graph illustrates that all three projects URV's are lowest when analysed over this period, the URV of desalination being as low as 530 cents/m^3 at a discount rate of 6%.

8.6 Calculations

Four linked Excel spreadsheets were used in the NPV economic analysis. These are Data_Input, Phase_1, Water_Transfer and Results_Output. The workings of these spreadsheets can be provided on request.

8.7 Conclusion

The results of the economic analysis (30 years) indicate that desalination is the most economic water supply alternative to augment the existing supply at Zinkwazi. The sensitivity analysis showed that this was also true over the shorter (20 years) and longer period of (40 years). All the projects were shown to be more economically viable when analysed over a 40-year life span.

CHAPTER 9

9 CONCLUSIONS

9.1 Water Shortages

Fresh water is not an abundant resource with only 2.77 % of global water being fresh, the rest being found in the oceans (Thomas and Cuccinello, 1998, paragraph 1). Competition and demand for water is increasing and it is predicted that by the year 2025, 48 countries and 2.8 billion people will be affected by water shortages, including South Africa (Winpenny, 2003, p.2). South Africa is already classified as a water-stressed country, as it has less then 1700 m^3 of water per person per year (Institute of Municipal Engineers of South Africa, 2001, p.4).

Zinkwazi like many other places in South Africa has a water supply problem, both from a quality and quantity perspective. The existing borehole supply is old and cannot meet the current and future demands of the town. This has lead to water restrictions and has retarded economic development and growth. The town also has no water treatment plant and the water quality does not meet potable water quality standards for some determinants.

9.2 Water Supply Alternatives Investigated

As traditional water supply approaches become less appropriate or more expensive, unconventional supply approaches are receiving more attention. Alternative water supply solutions including improved water use efficiencies, wastewater recycling and desalination are increasingly being used.

In an attempt to offer a possible solution to the water supply problems at Zinkwazi this study proposes the use of seawater desalination to meet the needs of the town. Desalination is becoming more economically viable and increasingly commonplace. The proximity of large portions of the world's population to the sea that live in coastal towns and cities, make desalination an ideal water supply technology (Wicks, 1999, cited in *Water International*, 1999, p.396). The costs of desalination have reduced significantly and are comparable in some cases to traditional methods of water supply. From an environmental perspective the benefits of desalination over traditional methods add weight to the argument for its increased use as providing water from desalination will alleviate the stress on fresh water systems making more water available for agriculture and the needs of ecosystems (Stikker, 2002, p.1).

Of the water supply options investigated for Zinkwazi, only the supply from Mandini / Tugela and Stanger were worth investigating further, along with desalination. The regional supply from Mvoti proved to be too expensive and the timing of this initiative does not match the immediate requirements of Zinkwazi. Groundwater potential was shown to be inadequate to meet future demands and was therefore not considered.

9.3 Potential of Seawater Desalination for Zinkwazi Town

Membrane technology, specifically RO has a number of advantages over other desalination technologies. Of particular relevance to Zinkwazi is the fact that RO plants have a small footprint that can blend in with the surrounding community, which is important for a holiday resort town. Membrane filtration plants are easier to operate and monitor and require less supervision than conventional plants (Elarde and Bergman, 2001, p.3). This would be advantageous to the Municipality, reducing labour and time costs. Membrane technology is well developed and can be regarded as a standard unit process known to perform to the required specifications (Ninham Shand, 2002a, p.21). As ESKOM (national power grid) is the cheapest available energy source at Zinkwazi and there are no major industries in the area that could be used as a heat source for thermal desalination processes, reverse osmosis was chosen as the preferred desalination technology for the study, because under these circumstances it is the most economical.

The use of locally manufactured GrahamTek membrane technology is recommended as it has a unique patented technology that does not require the use of pre-treatment chemicals thus reducing costs. Analysis has found that the GrahamTek technology also results in higher performance, energy efficiency and non-fouling (Water Sewage and Effluent, 1998, p.7). A site visit to a desalination plant at Albany Coast Water Board helped establish the credibility and operational track record of this technology where it has been used successfully for the past five years.

Beach-well abstractions are proposed for Zinkwazi. The use of a beach well seawater intake system reduces the capital costs of the intake and pre-treatment systems, and enhances the lifetime of the membranes, facilitates lower operation expenses and manpower, and reduces the amount of consumed chemicals. The saving in pre-treatment filtration equipment can also reduce the plant footprint, thus reducing total investment (Schwarz, 2000, p.51)

Two potential sites for the beach wells have been identified, one south of the town and the other north of the town on the banks of the Zinkwazi River. Both have their advantages and disadvantages, but further investigations, including an analysis of the porosity of the sands will have to be undertaken before any decision can be made.

The construction of a desalination plant at Zinkwazi benefits the environment as it reduces the abstraction of groundwater and negates the need for the construction of a dam or pipeline to supply water to Zinkwazi. Dams can have negative environmental impacts.

Chapter 7 detailed the benefits of appropriate environmental awareness and compliance through the undertaking of an EIA. Public participation is a vital component of any EIA (Paramjit Mahi, 2001, p.6). The problems pubic perceptions can have on the implementation and management of a desalination plant were highlighted by the experiences of the ACWB. Any measure to investigate desalination further at Zinkwazi should be accompanied by appropriate stakeholder participation. Issues or relevance include brine disposal and seawater intrusion into groundwater resources when using beach wells. Appropriate EIA's approved by the DAEA are essential.

9.4 Economic Analysis

An economic analysis was performed to determine the most viable water supply alternative. Results indicated that desalination was the most economically suitable alternative. The results confirmed what was indicated in the literature and has been stated in the desalination industry, namely, that desalination is a competitive alterative water supply technology. Costs of desalination have decreased over the last decade and are now comparable in some cases to those of traditional water supplies. Breakthroughs in reduced energy costs and investment costs for desalination processes have resulted in cost levels of \$0.40 to \$0.80/m^3 (R2.8 to R5.6) before distribution (Stikker, 2002, p.1).

The economic cashflows included the construction costs, replacement of mechanical and electrical equipment at the end of their economic lives, the annual operational costs and the annual energy costs of pumpsets. The analysis period was 30 yrs.

The results of the pre-feasibility level economic comparative analysis for the three alternative supply scenarios are tabulated below, see **Table 11.** The results of the economic analysis are also plotted to facilitate interpretation, see **Figure 10.**

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Scheme	Capital Cost (R'000)	Incremental yield ('000 m^3)	Net Present Value (R'000) at Discount Rates			Unit Reference Value (cents/m^3) at Discount Rates		
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NCSS to Zinkwazi	27 487	392	27 588	27 283	27 010	965	1200	1451

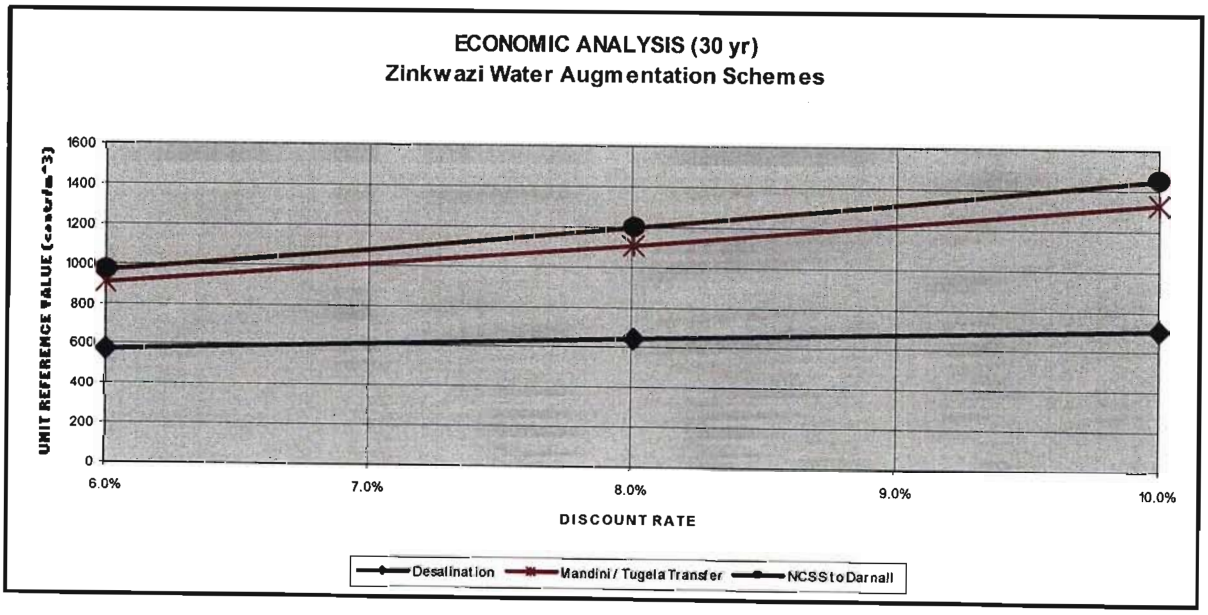

Figure 10: Economic Analysis Results (30 years)

With reference to the URV's presented in **Table 11** and **Figure 10** it clear that desalination represents the most economical means of augmenting supply to Zinkwazi. The URV's of desalination at the 6, 8 & 10% discount rates are significantly lower and therefore more economically viable compared with the other alternatives. For evaluation purposes the higher discount rate is conservatively used to account for possible difficulties in obtaining capital funding.

A sensitivity analysis undertaken by changing the period of analysis from 30 years to 20 and 40 years was also performed. The outcome of this did not affect the result and desalination still proved the most economical option. Extending the analysis period to 40 years did, however, improves the economic viability of the project.

The results of this analysis in favour of desalination can be considered conservative to some extent depending on the perspective taken. It could be argued that the cost of providing water from the bulk water transfer options is not a true reflection, as the cost of producing the water in these options is not included. In contrast, the cost of the desalination plant covers all costs of 'creating' freshwater from seawater, as well as treatment. A truer comparison of costs is between desalinated water and the development of 'new' water supplies (Arthur, 1997, paragraph 9).

The results at Zinkwazi mirror those obtained by Anglian Water in the United Kingdom, which indicate that a combination of local factors can decisively affect the economics of desalination. Anglian Water in the United Kingdom has a long coastline and its many visitors create a high summer demand. The infrastructure to meet this by extra water transfers would be expensive if it were needed for only four months of the year. The relatively high cost of meeting seasonal demand from seawater could be balanced against the high cost of measures to increase inland reserves (Arthur, 1997, paragraph 12).

Similarly to Anglian Water, the geographical location of Zinkwazi makes it remote from any existing bulk water infrastructure. The cost of transporting water from far away proved too expensive, combined with the fact that the demands at Zinkwazi are too low to warrant large capital expenditure on long pipelines. A site-specific solution like desalination is therefore more appropriate in this case. The argument made by Schutte (1983, p.10) that desalination represented a viable water supply alternative for small to medium towns, especially isolated coastal towns, has therefore been proved true.

9.5 Strategic Issues

9.5.1 Strategic Customer

As stated in the opening Chapter of this dissertation, Umgeni Water has a strategic objective relating to its customers, namely: -

Customer: To continuously improve customer satisfaction whilst growing and developing our customer base in our primary business

- Seek innovative products upstream and downstream to alleviate problems for existing customers.

Umgeni Water as a regional bulk water service provider to the Ilembe District Municipality, within which Zinkwazi falls, has a strategic interest in resolving the water supply problems at Zinkwazi, as the IDM is an important customer. Zinkwazi is a small community that in regional terms does not use a lot of water. Umgeni Water is therefore not going to make a lot of money from water sales if the organisation takes over the water supply to the town. Resolving the Municipalities water supply problems may, however, place Umgeni Water in good standing with the Municipality. This may in turn open the door to larger more lucrative bulk water supply agreements.

9.5.2 Commercial Business

The other strategic objective of Umgeni Water is to develop the organisations commercial interests both locally and internationally, as stated below:

Growth: To increase our geographic and development impact

- Position the commercial business of Umgeni Water as a significant strategic venture to meet the needs of its stakeholders.
- Develop Umgeni Water's regional, national, and international impact.

The desalination market is a growing one, expected to generate expenditures of US$95 billion from 2005 – 2015, mostly in the Middle East (International Desalination Association News, 2004, p.4). Desalination is also being investigated in South Africa, especially in areas with water shortages such as Cape Town and Port Elizabeth (Sonjica, 2005, paragraph 4). Consulting engineers Ninham Shand believe that with advances in RO technology, RO is

becoming a competitive process of water treatment which they expect will b
more in the future, both inland and at the coast in South Africa, (Tucker and
p.20).

Desalination is a growing industry and the opportunity exists for Umgeni Water to diversify into this field. Umgeni Water needs experience in desalination if it is going to make an impact in the desalination market. Owning or operating a desalination plant at Zinkwazi will provide the required stepping stone into the market and improve the organisations chances when tendering for desalination projects.

In summary this dissertation proposes the use of desalination to address the water supply shortages at Zinkwazi. An economic analysis was undertaken which showed that available traditional surface water supply solutions are far more expensive than desalination. Desalination technology, which has often been ignored in the past with claims that it is not economically competitive are clearly not valid. Desalination clearly has its place especially in site-specific situation such as Zinkwazi.

Part of the problem, however, as identified by Shields (1999, p.20) also lies in the prevalence of "old thinking" among water planners and managers. A concerted effort may therefore have to be made to market the findings of this investigation to decision makers.

CHAPTER 10

10 RECOMMENDATIONS

Although Stimela Bosch & Associates (2004, p.57) have mentioned desalination as a possible water supply alternative for Zinkwazi, this is this first study of its kind at Zinkwazi. The dissertation has, at a pre-feasibility level, proved the economic viability of desalination at Zinkwazi. An opportunity now exists for Umgeni Water to proactively pursue this initiative further.

10.1 Generic Recommendations for Desalination Projects

Except for regions where low energy prices prevail and/or where waste heat is available, RO is the most economical process for medium and large capacity seawater desalination plants, provided the seawater is not strongly polluted (Glueckstern, 1999, p.134).

It is generally accepted that feedwater quality has the strongest effect on the reliability and performance of RO plants. Seawater obtained directly from surface water always requires comprehensive pre-treatment such as media filtration, with or without chemical treatment and in many cases continuous or intermittent disinfection prior to final filtration (Glueckstern, 1999, 130).

According to recent studies, the cost difference between desalinated water from a medium size SWRO plant fed with high quality seawater from beach wells and water from a plant fed by an open surface intake is in the range of 1.5 –2.0 in favour of beach wells (Glueckstern, 1999, p.134).

Cogeneration is a process in which exhaust steam from electricity generating plants is used for another purpose. If a desalination plant uses cogeneration to supply part of its energy needs, the plant could reduce its demand for power (Pantell, 1993, paragraph 6).

The following can also be noted as being important facts regarding the economics of desalination (Abdulrazzak, Jurdi & Basma, 2002, p.396): -

- For small plants, automation may decrease the number of operators required but not necessarily their cost, inasmuch as more qualified staff will be required.
- In general costs decrease with increase in plant capacity.
- Desalination costs in Economic and Social Commission of Western Asia (ESCWA) member countries, can be distributed as follows:
    - 38 % for capital investment
    - 20.5 % for energy
    - 21.3 % labour
    - 16.2 % maintenance
    - 4 % chemicals

10.2 Recommendations for Zinkwazi

At the time of this study, electricity from the national grid is the only available energy source, resulting in the selection of membrane technology as the preferred and most economically viable technology for Zinkwazi.

Zinkwazi requires a water treatment plant with a small footprint that can blend in with a surrounding community. Membrane filtration typically requires less chemical addition then conventional processes, which results in smaller bulk chemical storage tanks and feed facilities.

Membrane filtration plants are easier to operate and monitor and require less supervision than conventional plants. Labour and general maintenance are fixed O&M costs, which will remain relatively constant independent of membrane plant size.

SWRO technology supplied by GrahamTek, a South African desalination plant manufacturer, is recommended for use in Zinkwazi. The technology was chosen as it represents a patented new desalination technology that does not require pre-treatment chemicals.

Two sites for the construction of the desalination plant have been identified. Further field investigations are required before any decision is made on which is more appropriate.

A comprehensive EIA is required before commencing with construction. This is essential and has the following benefits:

- Protects the environment
- Minimises planning approval timescales
- Minimises time for arranging funding
- Meets the environmental policy of sponsors and contractors
- Minimises overall construction timescales

10.3 Recommendations for Future Research at Zinkwazi

This study was conducted at a pre-feasibility level and therefore there are a number of areas where further investigation would provide greater insight into the potential costs of desalination at Zinkwazi. Areas that are recommended for further investigation include:

- Investigate the cost-benefits of blending desalinated water with the existing groundwater supply. The ACWB blends the product water from the desalination plant with groundwater obtained from its well field. As the cost of abstracting groundwater is generally cheaper than desalination, blending has the positive affect of reducing the water tariff to consumers.
- Investigate the possibility of abstracting water directly from the estuary as apposed to beach wells. The advantage of this is that the salinity of the estuary water is mush less (2000 mS/m) than seawater (35 000 mS/m) making it cheaper to purify. The disadvantage is that a direct abstraction will not have the filtering benefits of beach wells and therefore pre-treatment costs will be higher.

10.4 Recommendations for Umgeni Water

It is recommended that Umgeni Water approach the Ilembe District Municipality with a view to proposing desalination as a viable water supply alternative for Zinkwazi. Umgeni Water can offer its services to the Municipality to undertake a detailed desalination feasibility study.

It is recommended that Umgeni Water utilize its Process Services Department to construct a pilot desalination package plant on site at Zinkwazi. The Process Services Department has the expertise and infrastructure to undertake this project. The pilot desalination plant can be hired from desalination service provides or alternatively constructed at Umgeni Water's Process Evaluation Facility (PEF).

An operational package plant will provide valuable data on the possible quality of the product water that can be obtained using a beach well abstraction. The plant will also give an indication of O&M costs.

In offering to undertake such a study Umgeni Water's commitment to resolving the water supply problems will be evident to the Municipality and will also provide the organisation with valuable information to support any motivation for funding the implementation of a full-scale plant.

Before proceeding with the construction of a pilot plant it is essential that an appropriate public participation process be conducted to inform and obtain buy-in from residents and other stakeholders. Umgeni Water's environmental department is well equipped to undertake this aspect of any future work.

Strategically Umgeni Water will benefit from such an initiative, as it will provide the organisation with a much-needed track record for any future desalination tenders the organisation submits. It will also provide Umgeni Water with a head start over potential competitors who may offer desalination as a solution to Zinkwazi's water supply problems to the Municipality.

Providing a solution to the Municipalities water supply problems at Zinkwazi may have other benefits, by entrenching Umgeni Water's position as a reliable and innovative water services provider. This may lead to Umgeni Water being able to offer further services to the IDM, in particular the more lucrative bulk water supply contracts.

CHAPTER 11

11 REFERENCES

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ANNEXURE A

MEMBRANE PROCESSES: MEMBRANE TYPES AND CONFIGURATIONS

1. Membrane Types

- **Cellulose acetate:** One of the first commercially available membranes. Although newer membrane polymers have overshadowed its performance, it is still used for seawater, brackish water, and wastewater reclamation.
- **Polyamide:** Became the first to desalinate large volumes of seawater with a single pass through the membrane.
- **Thin film membranes:** Composed of a very thin layer of polymer cast over a porous substrate, this has become the most widely used membrane for seawater and brackish water desalination.

2. Configurations

- **Hollow fibre:** Thin, hair-like fibres are spun from polyamide (or cellulose trio-acetate) material, then bundled together in a cylindrical manner. Pressurized feedwater is introduced into the cylinder, causing water molecules to flow through the fibre walls to the hollow interior (lumen). The product water is conveyed through the lumen to a tube sheet on the end, which then empties into a cavity that collects the water prior to distribution through a manifold.
- **Spiral wound:** Flat sheet membranes (both cellulose acetate and thin film) are wound around a central product collection tube, alternately sandwiching plastic separators, which convey water to the central tube. The assembly is placed into a cylinder (pressure vessel) and feedwater is introduced. The feedwater flows between membrane envelopes, causing water to flow through the envelope into the product carrying spacer and then to the product collection tube. The spiral-wound membrane resembles a "jelly roll".

ANNEXURE B

THERMAL DISTILLATION PROCESSES

A brief description is given of the different distillation processes and their advantages and disadvantages, together with the process requirements, practical experience and, where applicable, economic considerations.

1. Multi-Stage Flash (MSF)

The basic principle is that the heated seawater enters the evaporation chamber under reduced pressure, resulting in flash boiling of part of the seawater. The vapour produced by flashing is then condensed on the outside of tubes conveying cooler seawater to the hot end of the plant (Schutte, 1983).

The incoming seawater passes through a heat rejection stage and is then heated in the heat recovery section of each subsequent stage. Before entering the first stage, the seawater is heated to its maximum temperature by external steam. The feed water then passes through the various stages where flashing takes place. The vapour passes through the demisters (to remove any entrained brine droplets) and is condensed (giving up its energy to heat the incoming brine flow) on the outside of tubes conveying seawater to the hot end of the plant. The fresh water formed by condensation is collected in each stage and is passed to subsequent stages where it is also flashed to recover heat for pre-heating of the feed water. This process of pressure reduction, flashing and condensation is then repeated all the way down the plant by both brine and distillate streams as they flow through the subsequent stages which are at successively lower pressures (Schutte, 1983).

The number of stages employed in the MSF process largely determines its efficiency, normally ranging from 20 to 50 stages for commercial plants. The more stages, the higher the fuel efficiency, but the higher the capital costs too. MSF plants are used exclusively for seawater desalination and have captured the largest part of this market by far. The main reasons why MSF has done so well, are that these plants can be constructed with large capacities (25 Mλ/d not being uncommon) and that the technology and expertise is available to construct much larger plants. Another main advantage is that boiling does not take place on the heating surface, but the seawater flash boils instead. These plants require well-trained operators and great care, especially during start-up and commissioning (Schutte, 1983).

2. Multiple Effect Evaporators / Boilers (MEB)

For this process, in each effect, steam is condensed on one side of a tube, with the heat of condensation utilised to evaporate water on the other side of the tube wall. The cascading use and re-use of the heat of vapourisation and condensation, is made possible by progressively reducing the pressure in each subsequent effect. This allows the brine to boil at progressively lower temperatures as it flows through the plant (Schutte, 1983). The multiple effect evaporation process usually operates on a once-through system and has no large mass of brine re-circulation around the plant. This reduces the pumping requirements and has a major (beneficial) effect on minimising scaling tendencies in the plant (Ninham Shand, 2002a)

Low-temperature multiple effect distillation offers a number of advantages, such as reduced scale forming and corrosion, but in spite of the potential advantages, it has not, to date, been used for large-scale applications (Schutte, 1983).

3. Vapour Compression (VC)

The vapour compression process differs from the other distillation processes in that it does not use an external heat source as its primary energy source. Instead, it utilises mechanical energy to drive a compressor (mechanical or thermo-compressor) to increase the vapour pressure of the water and thus its condensing temperature. Condensation takes place on one side of a tube, which acts as heat transfer surface, while feed water is evaporated by the heat of condensation on the other side of the tube. The compressor compresses the vapour, raising its condensation temperature and at the same time lowers the pressure on the feed water, thus reducing its boiling temperature. The only major energy input during the operation is that required to drive the compressor, since the heat of condensation and the vapourisation are being recycled across the heat transfer surface. Feed water heaters are normally only required during start-up and once the unit is running; only mechanical energy is required.

Two configurations used in vapour compression units are the vertical tube falling film and horizontal tube spray film types. A specialised type of vertical tube vapour compression plant is the brine concentrator. It comprises vertical titanium tubes through which the brine or seawater is re-circulated in a slurry containing calcium sulphates or other crystals. In this way scale formation on the heat transfer surfaces is minimised, since precipitation normally takes place on the crystal surfaces. Very high concentrations of dissolved solids can be handled in this way and water recovery of up to 98 % can be achieved.

Low-temperature vapour compression distillation for the desalination of seawater is highly efficient. It has a specific energy consumption of about 10 kWh/m^3, which is of the same order as for reverse osmosis without energy recovery. These plants operate within the temperature range of 30 to 70 °C, which results in low scaling and low corrosion rates and therefore require fairly simple feed water pre-treatment (Schutte, 1983).

ANNEXURE C

REFERENCE PLANT SITE VISIT

ALBANY COAST WATER BOARD DESALINATION PLANT SITE VISIT

Background

A visit to the Albany Coast Water Board (ACWB) at Boesmansrivier, Eastern Cape was made on the 26th June 2003. ACWB is one of only two water service providers in the country desalinating seawater for domestic consumption, the other being Robben Island.

One of the responsibilities of Planning Department is to scan the water sector environment for innovations and trends. Desalination has for a number of decades been a viable potable water supply source in many countries in the world. To date, however, its large-scale use has been precluded in South Africa due to the capital and operating costs relative to traditional water supply sources.

Indications are, however, that the cost of desalination is becoming comparable to the cost of existing water supply sources. This is especially true of surface water resource infrastructure such as dams, as the majority of the best dam sites have been used. The construction of new dams also faces strong environmental and social opposition, especially in developed countries (Simonovic, 2000).

Desalination thus needs to be investigated to determine its viability as a cost effective water supply solution. The site visit to ACWB thus represented an opportunity to see first hand a desalination plant in operation and to establish the effectiveness of its operation and the cost of supply.

Two members from Umgeni Water's Planning Department met with Mr. Ron Ball, the ACWB CEO and plant manager who provided the majority of information in this report.

Introduction

The ACWB serves the holiday resorts of Kenton-on-Sea and Boesmansrivier as well as the surrounding townships. The desalination plant is situated at the mouth of the Boesmansrivier estuary approximately 300 m from the river and 500 m from the Indian Ocean. The Boesmansrivier is a tidal river and is saline as far as 30 km upstream.

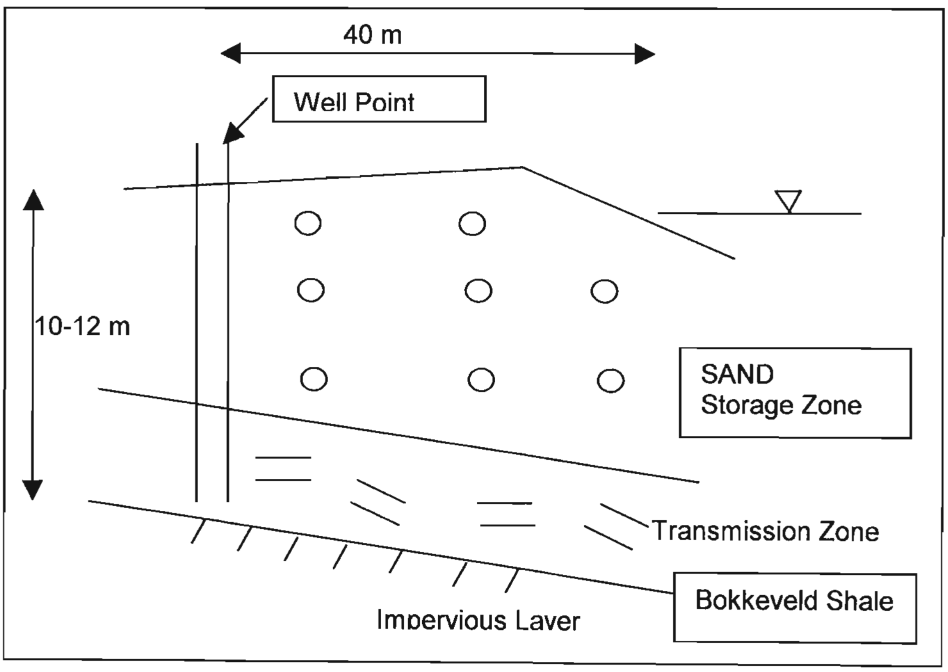
Historically the ACWB obtained its water from groundwater, but as demands increased the need for augmentation of the groundwater resource arose. As no other adequate groundwater resources are available in the area and with limits placed on the existing abstraction volumes the ACWB decided to install a desalination plant. The first desalination unit was installed in 1997.

International companies tendered for the contract but the lowest tender was received from Mineral Water Development (MWD) a South African company. MWD has developed a new Reverse Osmosis (RO) technology that eliminates the need for conventional chemical pre-treatment or post treatment. A GrahamTek CSW18 RO seawater desalinating plant of capacity 400 m^3/day (20-hr cycle) was installed.

Water Source

The ACWB relies on two raw water sources, which it blends to provide potable water for distribution. They are: -

- **Groundwater:** Coastal dune aquifer or Dias Cross well field (brackish water). This resource is a primary aquifer. The permitted abstraction is limited by DWAF to 21 l/s or 300 000 m^3/annum, to prevent over abstraction and the possibility of seawater ingress.
- **Saline water:** Saline water is abstracted from shallow beach wells located adjacent to the tidal river (Boesmansrivier) and the ocean **(Refer to Figure A & B)**. Nine (9) wells draw water through 40 m of sand (See schematic below for cross-section of well points). The wells are uPVC lined and 200 mm in diameter. The advantage of beach well abstraction is that the sand provides a natural filter and eliminates need for pre-treatment. A disadvantage of this system is that the abstraction rate is limited by the transmissivity of the sands and the number and diameter of the wells. As the seawater abstraction is limited the ACWB is investigating constructing a direct seawater intake so that they can increase the seawater abstraction capacity.



Tariff

- Bulk water tariff is R2.97/kl
- Borehole water costs R0.80/kl and Sea Water Reverse Osmosis (SWRO) water costs R4.50/kl. The ACWB blend the waters at 60:40 ratio to get bulk water tariff of R2.97/kl. The tariff will be increased to R3.12/kl in January 2004.
- Many residents have installed rainwater-harvesting systems, which can significantly reduce demand; hence there is an availability charge of R21/erf/month for high-income areas and R12/erf/month for low-income areas.

Demands

- AADD is 1 to 1.2 Ml/d, however, the peak over the December – January period is approximately 3 Ml/d.
- Available storage is 4Ml. Storage provision is in excess of 48 hours AADD, however holidays periods create significant peaks, where storage provision over these periods is reduced to 32 hours AADD. The Water Board, due to pumping from a single source, considers this provision inadequate. Despite DWAF (Nico Rabbie) disagreeing with the Water Board, the CEO (Ron Ball) feels that increased storage is necessary as the SWRO plant is highly technical and power outages occur frequently (Kenton-on-sea is at end of Eskom power reticulation, and the SWRO plant is the only large consumer).
- Demand projections done via extrapolating historical sales as well as using 'gut feel' estimate future growth at 3% p.a. No reliable information on population growth is available from the Municipality.

Operations

- **Staff:** Two (2) labourers, two (2) technician/operators, a CEO and secretary make up the staff compliment. The CEO stressed the importance of having the right people. The plant is manned by two operators working 8 hr shifts and one extra assistant during peak season.
- **Plant:** There are three (3) RO desalination plants with the following capacities: $25m^3/h$, $20m^3/h$ and 17 m^3/h. The first RO plant was installed in 1997 ($20m^3/h$) and is currently being upgraded **(Refer to Figure C & D)**.
- The plant operates for 12-14 hours per day normally, but 24 hours per day during peak season.
- The CEO highlighted the advantage of modular SWRO plants as there is more operational flexibility and other plants can cater for downtime in one plant.
- **Materials:** Due to the saline water all pipes and fittings are generally stainless steel (for pressures of approximately 60 bars) and uPVC. Local 316 stainless steel doesn't last as long as imported stainless steel, which is much better but more expensive. Due to the high pressures, leaks and holes sometimes occur in the plant. Repairing

leaks as soon as possible avoids excessive downtime and reduces the threat of a major pipe burst, which is always a safety concern.

- **Electronics:** Electronic problems are a major concern in the operation of the plant. SWRO desalination plants have sophisticated and expensive electronics as the plants effective operation is dependent on them. A recent lightning strike at the plant caused R90 000 damage to electronics (even though there is lightning and surge protection).
- **Membrane:** The membranes in the oldest plant have not been replaced since start-up, over 5 years ago. The CEO attributes this to good operation and maintenance (NB: right people who care) and the fact that chemicals are not used in pre-treatment.
- **Pumps:** Pump suppliers (International suppliers included) can sometimes make gross errors in the provision of their pumps. Even though the suppliers are aware that the pumps will be used for desalination and insist the pumps are manufactured entirely from stainless steel, ACWB has purchased pumps that have broken down shortly afterwards. The cause is often the result of a part being made of steel having corroded away very quickly, resulting in a breakdown. The installation of pumps has also proven problematic with poor installations resulting in vibration failure. Only when ACWB got assistance from Amotola Water and they installed the pumps with lasers were the problems resolved.
- The main inlet pump to the old plant (20 m^3/h), a 12-stage pump, **(Refer to Figure E)** which consumes approximately 285 amps, has a recovery turbine (generates 43kW). Without the recovery turbine, costs would be uneconomical. The motors for the pumps are covered to reduce noise pollution. The new plant (17 m^3/h) **(Refer to Figure F)** is powered by a Grunfos in-line multi stage pump.
- **Power:** ESKOM provides the power, although not very consistently as there are sometimes power outages and surges. Power problems are related to being at the end of ESKOM's reticulation line. A power surge results in the SWRO plant tripping; therefore full time operators to reset and restart the plant are needed.
- Approximately 80% of operating the plant is Electricity cost. The electricity bill varies between R22 000 and R35 000 per month. The pumping head from source to plant is approximately 12m and from the plant to reservoirs (4km) is approximately 90 m.
- At present only two out of three plants can operate simultaneously as there is insufficient ESKOM power. ESKOM charge more for the operation of two plants simultaneously, therefore only during off-peak periods does the ACWB use two (2) plants.
- **Telemetry:** Dias Cross is 9km from the plant therefore telemetry is required so that pumps can be operated from the plant. Some individual boreholes have meters, and there is a total outflow meter for the well field. Meter operation in beach well abstractions is problematic as sand ingress can result in inaccurate meter readings and breakdowns. The pumping system is automated according to the reservoir level.

Water Quality

- EC and pH are the main water quality constituents measured at the SWRO plant.
- Sodium hypo-chlorite is used as the disinfectant.
- Recovery rate is approximately 45% (potable water from saline water)
- Product water quality is usually around 600 ppm.
- It is better operationally to backwash every time the SWRO plant is stopped (cf. on start-up), as the membranes stay filled with fresh water when not in use.
- Detergent is used occasionally in rinse water e.g. biotex (similar to common household washing powder) to help with the cleaning. Other chemicals are used once a year.
- The plant brine is gravity fed back into the river at the estuary mouth via a small uPVC outlet pipe, which is only visible at low tide. No visible signs of the discharge were evident **(Refer to Figure G & H)**. There is, however, crustation growth on the outlet pipe that requires regular cleaning.
- The town is predominantly serviced by septic tanks (80%) or conservancy tanks. The township areas have small-bore sewerage systems. This is of concern to the ACWB as one township lies above the Dias Cross well field. No water quality problems with respect to sewerage ingress have, however, been experienced at the ground water well field to date.

Public Participation

- The CEO stressed the importance of addressing the social and environmental issues upfront with respect to any new developments. Generally the major problems occur from uninformed ratepayers that need to be educated about desalination, especially with respect to brine discharge.
- The regulators (DWAF and DEAT) are also ill informed and appear to make snap judgements based on no scientific evidence, according to Mr. Ball. A prime example is that Environmental Affairs want the brine outlet pipe removed from its current position so that it spills out onto a beach, presumably less visible to the public.
- DWAF also used to charge for seawater abstraction, before the ACWB protested.

Conclusions

The ACWB successful implementation and operation of desalination technology has allowed the Water Board to meet growing demands and ensure a reliable and high quality water supply to its customers for 6 years. With no other local water resources available and the unlikelihood of supply from a large regional scheme, desalination has proven to be somewhat of a saviour.

The ACWB have managed to maintain an affordable tariff of R2.97 by blending desalination product water with existing groundwater supplies, although one might argue that given no other source of water supply R4.50/kl for desalination water is not an unreasonable charge.

From the site visit it can be concluded that given particular circumstances desalination is eminently feasible and affordable for some South African situations. It is thus recommended that for particular water supply situations, especially coastal resort towns, desalination should be considered as a future source of potable water.

A prime example is Zinkwazi on the KwaZulu-Natal North Coast, which has for some time suffered from water shortages during peak months. Its isolation from any regional water supply source and a limited groundwater supply make its water supply situation very similar to that of Kenton-on-Sea. It is therefore not unreasonable to assume that desalination may also represent a feasible water supply alternative for Zinkwazi.

Way Forward

It is thus recommended that as part of ongoing infrastructure planning for the north coast area the cost effectiveness of using desalination to supply the town of Zinkwazi be assessed at a pre-feasibility level of detail by the Planning Department.

The output from this investigation will provide:

- A possible solution to the town of Zinkwazi's water supply problems
- A benchmark as to the feasibility of using desalination as an alternative water supply

Acknowledgements

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Planning Engineer	Hydrogeologist
Angus Nicoll	Graham Metcalf

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Cc: Pumezo Jonas
Steve Gillham
Dave Nosaic

ANNEXURE D

FIGURE 3: LOCALITY MAP OF PROPOSED WATER SUPPLY INFRASTRUCTURE

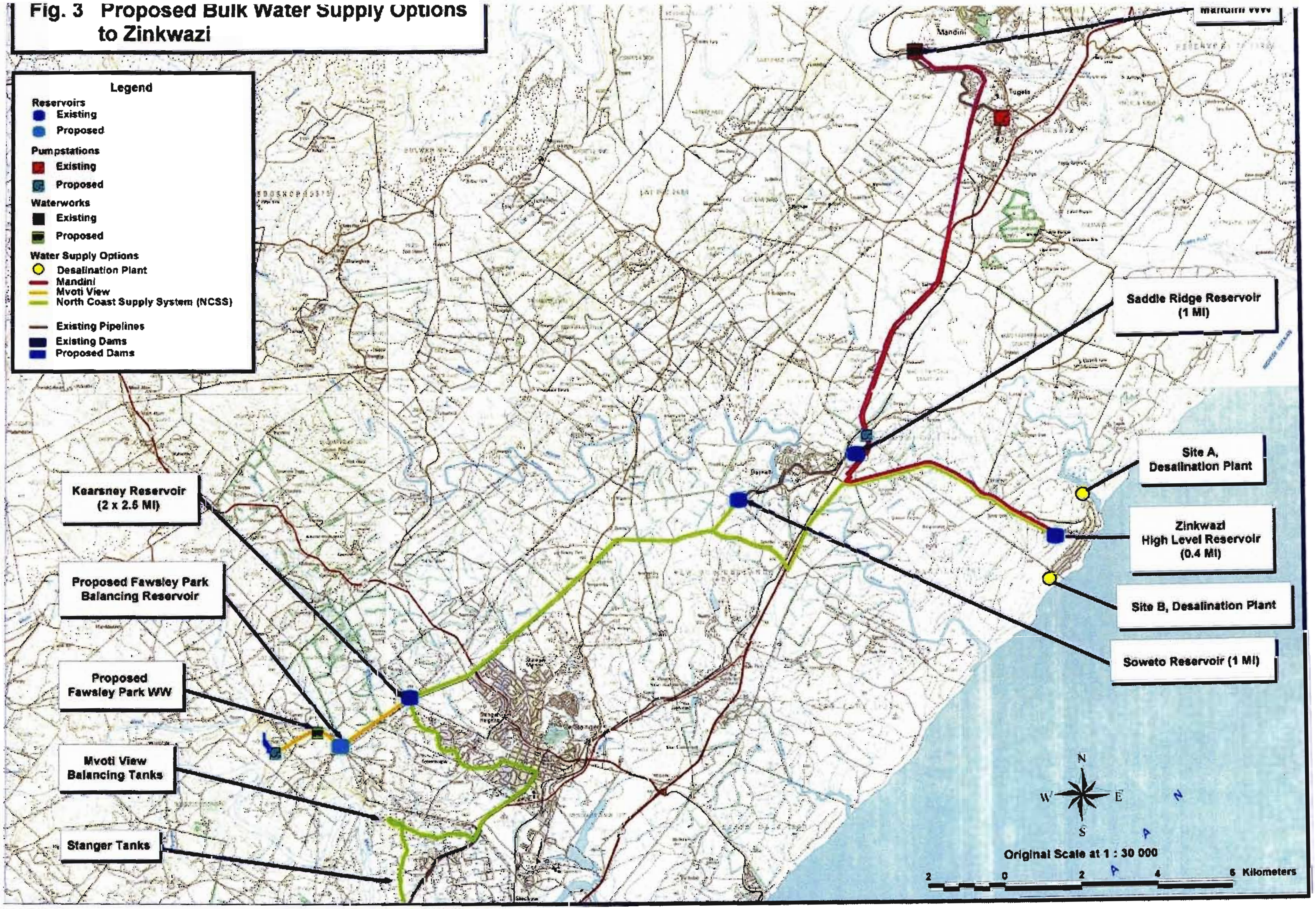


Fig. 3 Proposed Bulk Water Supply Options to Zinkwazi

ANNEXURE E

INFRASTRUCTURE COSTS

Project Costs for Economic Assessment **Costs @ 2003**

Nine production beach wells pumping seawater
to Reverse Osmosis Desalination Plant

Zinkwazi Desalination Plant	**Capital Costs (Rands)**	**Design Life (Yrs)**
Civil Works		
1.5 Ml/day Desalination Plant	R 3,930,000	30
9 No.Beach Wells @ 168kl/day/bh or 1512kl/day	R 675,000	15
8' Diameter		
Bulk rising mains from beach wells to desalination	R 315,000	30
plant HDPE 63mm x 9km		
Mechanical and Electrical		
9 No. Borehole Pumps	R 540,000	15
Total	**R 5,460,000**	
P&G's (20%)	R 1,092,000	
Sub-total	**R 6,552,000**	
Contingencies (10%)	R 655,200	
Sub-total	**R 7,207,200**	
Environmental fees (7%)	R 504,504	
Professional fees (12%)	R 864,864	
Total	**R 8,576,568**	
Construction Period	1	
Yield	**1500 kl/day**	

Project Costs for Economic Assessment **Costs @ 2003**

Potable water would be pumped from the upgraded Tugela Filtration Plant to Darnall's Saddle Ridge Reservoir and gravity fed to Zinkwazi

Tugela filtration plant upgrade and bulk rising main to Zinkwazi	**Capital Costs (Rands)**	**Design Life (Yrs)**
Civil Works		
Upgrade filtration plant from 1500 kl/day	R 364,981	30
to 3 000 kl/d.		
Bulk rising main from filtration plant to		
Darnall's Saddle Ridge Reservoir and Zinkwazi		
200 NB x 20.5 km	R 13,266,269	30
Mechanical and Electrical		
Upgrade pump stataion at w.t.w and		
including booster pump-statiom const.	R 1,665,619	15
Total	**R 15,296,868**	
P&G's (20%)	R 3,059,374	
Sub-total	**R 18,356,242**	
Contingencies (10%)	R 1,835,624	
Sub-total	**R 20,191,866**	
Environmental fees (7%)	R 1,413,431	
Professional fees (12%)	R 2,423,024	
Total	**R 24,028,321**	
Construction Period	**2.00**	
Yield	**1500 kl/day**	

Project Costs for Economic Assessment **Costs @ 2003**

Potable water gravity fed from Umgnei Water's
North Coast Supply System (NCSS) to Zinkwazi

NCSS to Zinkwazi	**Capital Costs (Rands)**	**Design Life (Yrs)**
Civil Works		
3.6 Ml reinforced concrete reservoir	4,028,790	30
400 NB x 3 100 m pipeline from Kearsney to		
Stanger high ridge off-take	3,894,260	30
200 NB x 7 500 m pipeline from Stanger		
High Ridge off-take to Soweto Reservoir	4,855,140	30
150 NB x 11 400 m pipeline from Soweto	4,720,421	30
Reservoir off-take to Zinkwazi		
Total	**17,498,610**	
P&G's (20%)	3,499,722	
Sub-total	**20,998,332**	
Contingencies (10%)	2,099,833	
Sub-total	**23,098,166**	
Environmental fees (7%)	1,616,872	
Professional fees (12%)	2,771,780	
Total	**27,486,817**	
Construction Period	**2**	
Yield	**1 075kl/day**	

ANNEXURE F

PERFORMANCE COMPARISON OF GRAHAMTEK DESALINATION PLANT

COST & OPERATIONAL ADVANTAGES OF GRAHAMTEK OVER COMPETITOR SYSTEMS

	COST CATEGORY	COMPETITOR	MWD	COMMENT
1	Chemical Pre-Treatment	YES	NONE	No chemical pre-treatment is required for the ***Graham Tek***™ pre –filtration system
2	Chemical Post Treatment	YES	NONE	The combination of the effects of the flow distributor electromagnetic field prevent membrane fouling and produces water free of all viruses and bacteria – therefore no post treatment is required
3	Chemical Membrane Washing	YES	NONE	The patented electro-magnetic defouling device prevents fouling which eliminates chemical cleansing
4	Chemical Waste Disposal	YES	NONE	As the MPD 1 systems do not require any chemicals whatsoever, chemical waste disposal is not an issue, neither is the storage of any chemicals.
5	Membrane Washing Downtime	YES	NONE	The membranes are self-cleansing during operation, therefore no membrane downtime is experienced
6	Membrane Replacement Costs	2x	1x	Membranes utilized in the ***Graham Tek***™ plants are estimated to last twice as long as membranes in conventional systems
7	Adverse Environmental Effects of Chemical Waste Disposal	YES	NONE	***Graham Tek's*** ™ is the only Plant in the World which is considered to be entirely Environmental friendly, as no chemicals are used. The brine reject can safely be disposed of in the sea
8	Membrane Performance: 'Flux'	MEDIUM	HIGH	Achieves 35% higher flux rates on seawater membranes than it's nearest Competitor – in a single pass operation.
9	Number of Membranes	6 to 7	2	For every 2 membranes used by ***Graham Tek***™, competitors use 6 –7 membranes to achieve the same results (Flux)
10	Operating Pressures	65 – 75 bar	58-62 bar	***Graham Tek***™ Flow distributor and EMF device contributes to lower operating pressures - saving on consumption
11	Energy consumption	To 7Kw.h	3.7 to kWh	***MWD*** utilises own power saving speed drive design on Electric Motors. Preventing overdrive peaks – saving power

ANNEXURE G

LOCATION OF POTENTIAL DESALINATION PLANT SITES

Figure 4: Proposed Zinkwazi Desalination Plant at Site A

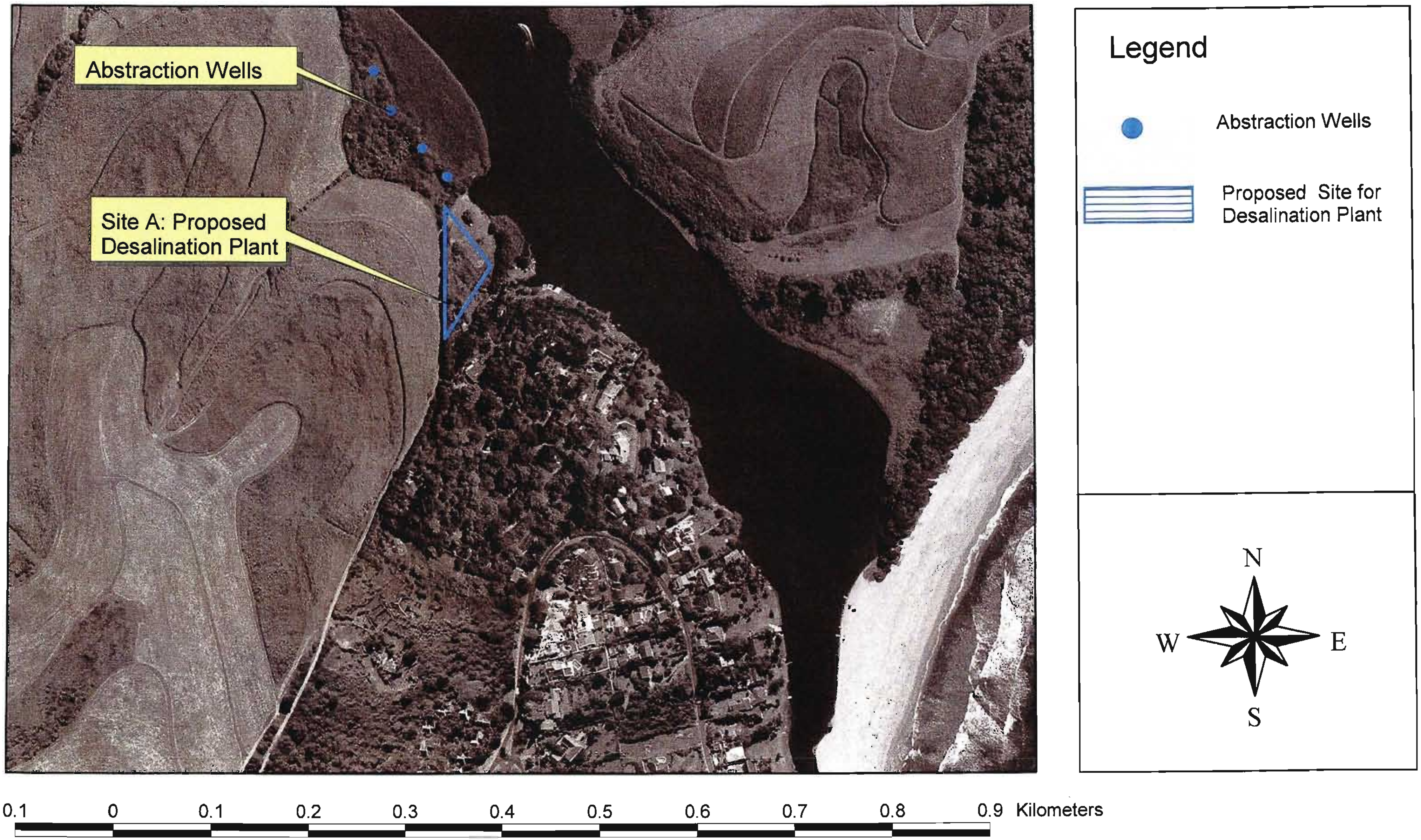
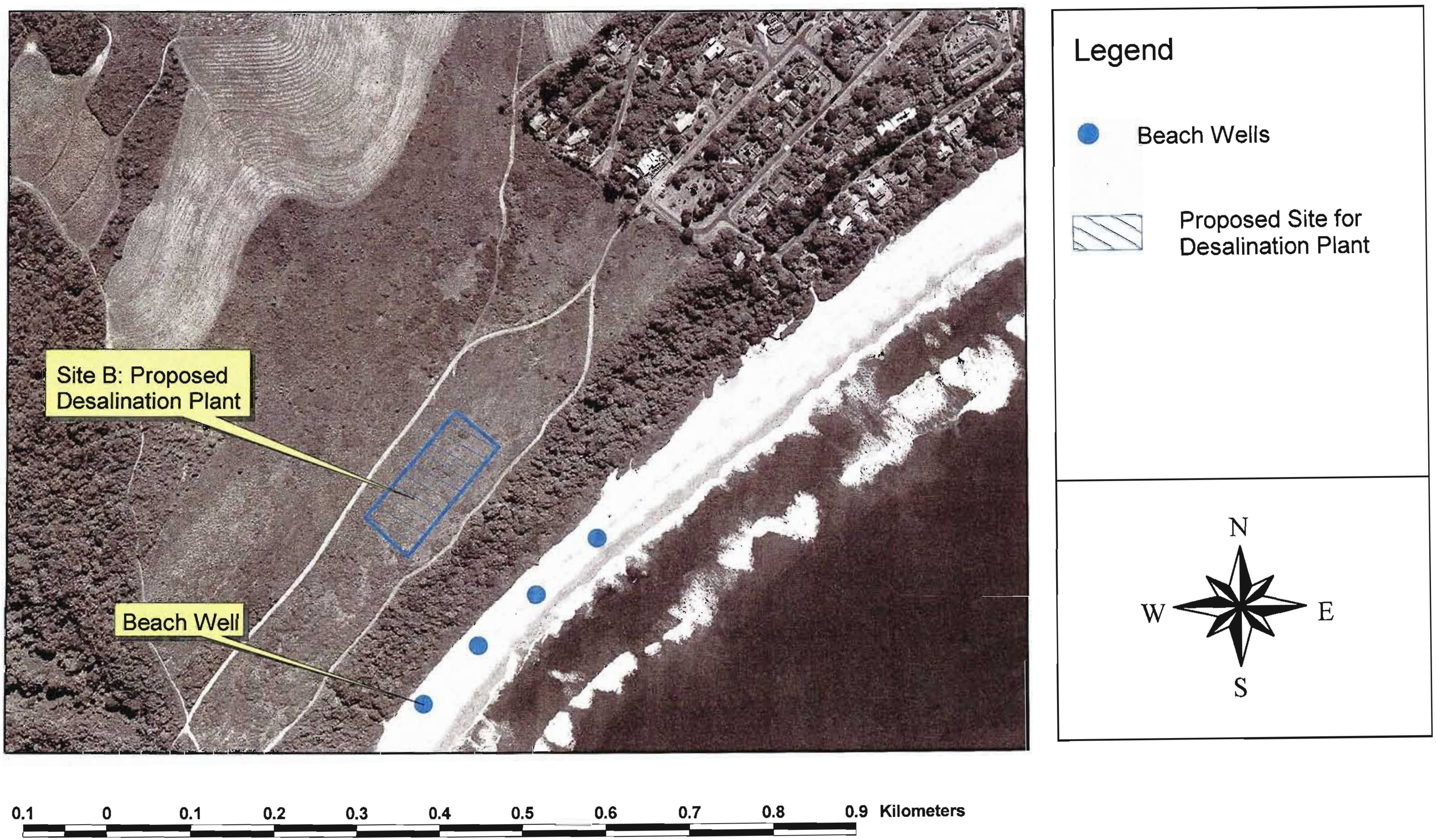


Figure 5: Proposed Zinkwazi Desalination Plant at Site B



ANNEXURE H

ECONOMIC ANALYSIS

Project Name	Dissertation	File Name	ECO_01Desalination.xls
Option	Desalination	Date	01-Jan-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.019

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks	Desalinatic	Zinkwazi Desalination Plant		1500.00	7,728			2004	2004	1	10.0%	7,728.3	0.0	6,955.5	0.0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline										1		0.0	0.0	0.0	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station	Boreholes	Beach Wells	9.00	1512.00		848	921	2004	2004	1	10.0%	0.0	848.2	0.0	763.4
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					7,728	848	921								
					8,577										

Year	Cost Factors	
	Social & Environ.	Admin.
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	4.00%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	**Period (yrs)**	**%**
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity		
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

Dissertation
Desalination

Analysis Period 20 years

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	8,577	0	0	8,577	0	0	8,091	0	0	7,941	0	0	7,797	0	0
2005	0	343	212	0	343	212	0	305	189	0	294	182	0	284	175
2006	0	343	221	0	343	221	0	288	185	0	272	175	0	258	166
2007	0	343	230	0	343	230	0	272	182	0	252	169	0	234	157
2008	0	343	239	0	343	239	0	256	178	0	233	162	0	213	148
2009	0	343	248	0	343	248	0	242	174	0	216	156	0	194	140
2010	0	343	257	0	343	257	0	228	171	0	200	150	0	176	132
2011	0	343	266	0	343	266	0	215	167	0	185	144	0	160	124
2012	0	343	275	0	343	275	0	203	163	0	172	138	0	145	117
2013	0	343	285	0	343	285	0	192	159	0	159	132	0	132	110
2014	0	343	295	0	343	295	0	181	155	0	147	126	0	120	103
2015	0	343	304	0	343	304	0	170	151	0	136	121	0	109	97
2016	0	343	314	0	343	314	0	161	147	0	126	116	0	99	91
2017	0	343	325	0	343	325	0	152	144	0	117	111	0	90	85
2018	0	343	335	0	343	335	0	143	140	0	108	106	0	82	80
2019	0	470	345	0	470	345	0	185	136	0	137	101	0	102	75
2020	0	343	356	0	343	356	0	127	132	0	93	96	0	68	70
2021	0	343	367	0	343	367	0	120	128	0	86	92	0	62	66
2022	0	343	378	0	343	378	0	113	125	0	79	88	0	56	62
2023	**0**	**343**	**389**	**0**	**343**	**389**	**0**	**107**	**121**	**0**	**74**	**83**	**0**	**51**	**58**
2024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**8,577**	**6,645**	**5,639**	**8,577**	**6,645**	**5,639**	**8,091**	**3,661**	**2,948**	**7,941**	**3,088**	**2,446**	**7,797**	**2,637**	**2,056**

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	14,701	2.2	673
8%	13,475	1.9	727
10%	12,490	1.6	782

Commission date 2004

Transfer capacity (m^3/s) 0.02

Check: 8,577

Project Name	Dissertation	File Name	ECO_01Desalination.xls
Option	Desalination	Date	01-Jul-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.019

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks	Desalinatic	Zinkwazi Desalination Plant		1500.00	7,728			2004	2004	1	10.0%	7,728.3	0.0	6,955.5	0.0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline										1		0.0	0.0	0.0	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station	Boreholes	Beach Wells	9.00	1512.00		848	921	2004	2004	1	10.0%	0.0	848.2	0.0	763.4
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					7,728	848	921								
					8,577										

Year	Cost Factors	
	Social & Environ.	Admin.
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	4.00%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	30 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

Dissertation
Desalination — Analysis Period 30 years

Year	Phase 1 Capital	Phase 1 Operation & Maintenance	Phase 1 Electricity	Total Annual Cost Capital	Total Annual Cost Operation & Maintenance	Total Annual Cost Electricity	NPV Cost (1994) @ 6% Capital	NPV Cost (1994) @ 6% Operation & Maintenance	NPV Cost (1994) @ 6% Electricity	NPV Cost (1994) @ 8% Capital	NPV Cost (1994) @ 8% Operation & Maintenance	NPV Cost (1994) @ 8% Electricity	NPV Cost (1994) @ 10% Capital	NPV Cost (1994) @ 10% Operation & Maintenance	NPV Cost (1994) @ 10% Electricity
Shadow	1	1	1	1	1	1									
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	8,577	0	0	8,577	0	0	8,091	0	0	7,941	0	0	7,797	0	0
2005	0	343	212	0	343	212	0	305	189	0	294	182	0	284	175
2006	0	343	221	0	343	221	0	288	185	0	272	175	0	258	166
2007	0	343	230	0	343	230	0	272	182	0	252	169	0	234	157
2008	0	343	239	0	343	239	0	256	178	0	233	162	0	213	148
2009	0	343	248	0	343	248	0	242	174	0	216	156	0	194	140
2010	0	343	257	0	343	257	0	228	171	0	200	150	0	176	132
2011	0	343	266	0	343	266	0	215	167	0	185	144	0	160	124
2012	0	343	275	0	343	275	0	203	163	0	172	138	0	145	117
2013	0	343	285	0	343	285	0	192	159	0	159	132	0	132	110
2014	0	343	295	0	343	295	0	181	155	0	147	126	0	120	103
2015	0	343	304	0	343	304	0	170	151	0	136	121	0	109	97
2016	0	343	314	0	343	314	0	161	147	0	126	116	0	99	91
2017	0	343	325	0	343	325	0	152	144	0	117	111	0	90	85
2018	0	343	335	0	343	335	0	143	140	0	108	106	0	82	80
2019	0	470	345	0	470	345	0	185	136	0	137	101	0	102	75
2020	0	343	356	0	343	356	0	127	132	0	93	96	0	68	70
2021	0	343	367	0	343	367	0	120	128	0	86	92	0	62	66
2022	0	343	378	0	343	378	0	113	125	0	79	88	0	56	62
2023	0	343	389	0	343	389	0	107	121	0	74	83	0	51	58
2024	0	343	400	0	343	400	0	101	118	0	68	79	0	46	54
2025	0	343	411	0	343	411	0	95	114	0	63	76	0	42	51
2026	0	343	423	0	343	423	0	90	111	0	58	72	0	38	47
2027	0	343	435	0	343	435	0	85	107	0	54	69	0	35	44
2028	0	343	447	0	343	447	0	80	104	0	50	65	0	32	41
2029	0	343	459	0	343	459	0	75	101	0	46	62	0	29	39
2030	0	343	471	0	343	471	0	71	98	0	43	59	0	26	36
2031	0	343	484	0	343	484	0	67	95	0	40	56	0	24	34
2032	0	343	496	0	343	496	0	63	92	0	37	53	0	22	31
2033	**0**	**343**	**509**	**0**	**343**	**509**	**0**	**60**	**89**	**0**	**34**	**51**	**0**	**20**	**29**
2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	8,577	10,076	10,174	8,577	10,076	10,174	8,091	4,449	3,976	7,941	3,582	3,088	7,797	2,950	2,462

Commission date: 2004
Transfer capacity (m^3/s): 0.02

Check: 8,577

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	16,516	2.9	578
8%	14,611	2.3	642
10%	13,209	1.9	709

Project Name	Dissertation	File Name	ECO_01Desalination.xls		
Option	Desalination	Date	01-Jul-03		
Base Year	2003	Component Life	30		

Phase	1	Commission Year	2004	Output (m^3/s)	0.019

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks	Desalinatio	Zinkwazi Desalination Plant		1500.00	7,728	0		2004	2004	1	10.0%	7,728.3	0.0	6,955.5	0.0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline										1		0.0	0.0	0.0	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station	Boreholes	Beach Wells	9.00	1512.00		848	921	2004	2004	1	10.0%	0.0	848.2	0.0	763.4
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					7,728	848	921								
					8,577										

Year	Cost Factors	
	Social & Environ.	Admin.
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	4.00%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	40 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

Dissertation
Desalination — Analysis Period 40 years

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	8,577	0	0	8,577	0	0	8,091	0	0	7,941	0	0	7,797	0	0
2005	0	343	212	0	343	212	0	305	189	0	294	182	0	284	175
2006	0	343	221	0	343	221	0	288	185	0	272	175	0	258	166
2007	0	343	230	0	343	230	0	272	182	0	252	169	0	234	157
2008	0	343	239	0	343	239	0	256	178	0	233	162	0	213	148
2009	0	343	248	0	343	248	0	242	174	0	216	156	0	194	140
2010	0	343	257	0	343	257	0	228	171	0	200	150	0	176	132
2011	0	343	266	0	343	266	0	215	167	0	185	144	0	160	124
2012	0	343	275	0	343	275	0	203	163	0	172	138	0	145	117
2013	0	343	285	0	343	285	0	192	159	0	159	132	0	132	110
2014	0	343	295	0	343	295	0	181	155	0	147	126	0	120	103
2015	0	343	304	0	343	304	0	170	151	0	136	121	0	109	97
2016	0	343	314	0	343	314	0	161	147	0	126	116	0	99	91
2017	0	343	325	0	343	325	0	152	144	0	117	111	0	90	85
2018	0	343	335	0	343	335	0	143	140	0	108	106	0	82	80
2019	0	470	345	0	470	345	0	185	136	0	137	101	0	102	75
2020	0	343	356	0	343	356	0	127	132	0	93	96	0	68	70
2021	0	343	367	0	343	367	0	120	128	0	86	92	0	62	66
2022	0	343	378	0	343	378	0	113	125	0	79	88	0	56	62
2023	0	343	389	0	343	389	0	107	121	0	74	83	0	51	58
2024	0	343	400	0	343	400	0	101	118	0	68	79	0	46	54
2025	0	343	411	0	343	411	0	95	114	0	63	76	0	42	51
2026	0	343	423	0	343	423	0	90	111	0	58	72	0	38	47
2027	0	343	435	0	343	435	0	85	107	0	54	69	0	35	44
2028	0	343	447	0	343	447	0	80	104	0	50	65	0	32	41
2029	0	343	459	0	343	459	0	75	101	0	46	62	0	29	39
2030	0	343	471	0	343	471	0	71	98	0	43	59	0	26	36
2031	0	343	484	0	343	484	0	67	95	0	40	56	0	24	34
2032	0	343	496	0	343	496	0	63	92	0	37	53	0	22	31
2033	0	343	509	0	343	509	0	60	89	0	34	51	0	20	29
2034	0	470	522	0	470	522	0	77	86	0	43	48	0	25	27
2035	0	343	536	0	343	536	0	53	83	0	29	46	0	16	25
2036	0	343	549	0	343	549	0	50	80	0	27	43	0	15	24
2037	0	343	563	0	343	563	0	47	78	0	25	41	0	13	22
2038	0	343	577	0	343	577	0	45	75	0	23	39	0	12	21
2039	0	343	591	0	343	591	0	42	72	0	21	37	0	11	19
2040	0	343	605	0	343	605	0	40	70	0	20	35	0	10	18
2041	0	343	619	0	343	619	0	37	68	0	18	33	0	9	17
2042	0	343	634	0	343	634	0	35	65	0	17	32	0	8	15
2043	**0**	**343**	**649**	**0**	**343**	**649**	**0**	**33**	**63**	**0**	**16**	**30**	**0**	**8**	**14**
2044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	8,577	13,634	16,018	8,577	13,634	16,018	8,091	4,909	4,716	7,941	3,822	3,472	7,797	3,077	2,664

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	17,716	3.3	530
8%	15,235	2.5	603
10%	13,538	2.0	679

Commission date 2004
Transfer capacity (m^3/s) 0.02

Check: 8,577

Project Name	DISSERTATION		File Name	ECO_05Mandini.xls	
Option	Option Mandini / Tugela Transfer		Date	01-Jul-04	
Base Year	2003		Component Life	30	

Phase	1	Commission Year	2004	Output (m^3/s)	0.017

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks											10.0%	0	0	0	0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline	Steel	Mandini / Tugela Transfer	200.00	20500.00	21,412			2003	2004	2	20.0%	12,847.2	0.0	8,564.8	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station		Upgrade pumpstation				2,616	79	2004	2004	1		0.0	2,616.4	0.0	2,616.4
Infrastructure															
Infrastructure															
Advance infr											10.0%	0	0	0	0
Advance Infr															
Total					21,412	2,616	79								
					24,028										

Year	Cost Factors	
	Social & Environ.	Admin.
0	0.000	
1	0.000	
2	0.000	
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	0.25%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	20 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

DISSERTATION

Option Mandini / Tugela Transfer   Analysis Period 20 years

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	12,847	0	0	12,847	0	0	12,847	0	0	12,847	0	0	12,847	0	0
2004	11,181	0	0	11,181	0	0	10,548	0	0	10,353	0	0	10,165	0	0
2005	0	158	20	0	158	20	0	141	18	0	136	17	0	131	17
2006	0	158	21	0	158	21	0	133	18	0	126	17	0	119	16
2007	0	158	22	0	158	22	0	125	17	0	116	16	0	108	15
2008	0	158	23	0	158	23	0	118	17	0	108	15	0	98	14
2009	0	158	24	0	158	24	0	112	17	0	100	15	0	89	13
2010	0	158	24	0	158	24	0	105	16	0	92	14	0	81	13
2011	0	158	25	0	158	25	0	99	16	0	85	14	0	74	12
2012	0	158	26	0	158	26	0	94	16	0	79	13	0	67	11
2013	0	158	27	0	158	27	0	88	15	0	73	13	0	61	10
2014	0	158	28	0	158	28	0	83	15	0	68	12	0	55	10
2015	0	158	29	0	158	29	0	79	14	0	63	12	0	50	9
2016	0	158	30	0	158	30	0	74	14	0	58	11	0	46	9
2017	0	158	31	0	158	31	0	70	14	0	54	11	0	42	8
2018	0	158	32	0	158	32	0	66	13	0	50	10	0	38	8
2019	0	551	33	0	551	33	0	217	13	0	161	10	0	120	7
2020	0	158	34	0	158	34	0	59	13	0	43	9	0	31	7
2021	0	158	35	0	158	35	0	55	12	0	40	9	0	28	6
2022	0	158	36	0	158	36	0	52	12	0	37	8	0	26	6
2023	**0**	**158**	**37**	**0**	**158**	**37**	**0**	**49**	**12**	**0**	**34**	**8**	**0**	**24**	**6**
2024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2033	**0**	0	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**24,028**	**3,398**	**538**	**24,028**	**3,398**	**538**	**23,395**	**1,820**	**281**	**23,200**	**1,521**	**233**	**23,012**	**1,288**	**196**

Commission date 2004

Transfer capacity (m^3/s) 0.017

Check: 24,028

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	25,496	2.2	1167
8%	24,955	1.9	1346
10%	24,496	1.6	1535

Project Name	DISSERTATION	File Name	ECO_05Mandini.xls
Option	Option Mandini / Tugela Transfer	Date	01-Jul-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.017

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks											10.0%	0	0	0	0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline	Steel	Mandini / Tugela Transfer	200.00	20500.00	21,412			2003	2004	2	20.0%	12,847.2	0.0	8,564.8	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station		Upgrade pumpstation				2,616	79	2004	2004	1		0.0	2,616.4	0.0	2,616.4
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					21,412	2,616	79								
					24,028										

Year	Cost Factors	
	Social & Environ.	Admin.
0	0.000	
1	0.000	
2	0.000	
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	0.25%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	30 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

DISSERTATION

Option Mandini / Tugela Transfer **Analysis Period 30 years**

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	12,847	0	0	12,847	0	0	12,847	0	0	12,847	0	0	12,847	0	0
2004	11,181	0	0	11,181	0	0	10,548	0	0	10,353	0	0	10,165	0	0
2005	0	158	20	0	158	20	0	141	18	0	136	17	0	131	17
2006	0	158	21	0	158	21	0	133	18	0	126	17	0	119	16
2007	0	158	22	0	158	22	0	125	17	0	116	16	0	108	15
2008	0	158	23	0	158	23	0	118	17	0	108	15	0	98	14
2009	0	158	24	0	158	24	0	112	17	0	100	15	0	89	13
2010	0	158	24	0	158	24	0	105	16	0	92	14	0	81	13
2011	0	158	25	0	158	25	0	99	16	0	85	14	0	74	12
2012	0	158	26	0	158	26	0	94	16	0	79	13	0	67	11
2013	0	158	27	0	158	27	0	88	15	0	73	13	0	61	10
2014	0	158	28	0	158	28	0	83	15	0	68	12	0	55	10
2015	0	158	29	0	158	29	0	79	14	0	63	12	0	50	9
2016	0	158	30	0	158	30	0	74	14	0	58	11	0	46	9
2017	0	158	31	0	158	31	0	70	14	0	54	11	0	42	8
2018	0	158	32	0	158	32	0	66	13	0	50	10	0	38	8
2019	0	551	33	0	551	33	0	217	13	0	161	10	0	120	7
2020	0	158	34	0	158	34	0	59	13	0	43	9	0	31	7
2021	0	158	35	0	158	35	0	55	12	0	40	9	0	28	6
2022	0	158	36	0	158	36	0	52	12	0	37	8	0	26	6
2023	0	158	37	0	158	37	0	49	12	0	34	8	0	24	6
2024	0	158	38	0	158	38	0	47	11	0	31	8	0	21	5
2025	0	158	39	0	158	39	0	44	11	0	29	7	0	19	5
2026	0	158	40	0	158	40	0	41	11	0	27	7	0	18	5
2027	0	158	41	0	158	41	0	39	10	0	25	7	0	16	4
2028	0	158	43	0	158	43	0	37	10	0	23	6	0	15	4
2029	0	158	44	0	158	44	0	35	10	0	21	6	0	13	4
2030	0	158	45	0	158	45	0	33	9	0	20	6	0	12	3
2031	0	158	46	0	158	46	0	31	9	0	18	5	0	11	3
2032	0	158	47	0	158	47	0	29	9	0	17	5	0	10	3
2033	**0**	**158**	**49**	**0**	**158**	**49**	**0**	**28**	**8**	**0**	**16**	**5**	**0**	**9**	**3**
2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**24,028**	**4,980**	**970**	**24,028**	**4,980**	**970**	**23,395**	**2,183**	**379**	**23,200**	**1,749**	**295**	**23,012**	**1,433**	**235**

Commission date 2004

Transfer capacity (m^3/s) 0.017

Check: 24,028

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	25,957	2.9	908
8%	25,244	2.3	1110
10%	24,679	1.9	1325

Project Name	DISSERTATION	File Name	ECO_05Mandini.xls
Option	Option Mandini / Tugela Transfer	Date	01-Jul-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.017

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
Waterworks				Cap.							10.0%	0	0	0	0
Tunnel			Dia.	Length							20.0%	0	0	0	0
Pipeline	Steel	Mandini / Tugela Transfer	Dia. 200.00	Length 20500.00	21,412			2003	2004	2	20.0%	12,847.2	0.0	8,564.8	0.0
Dam			FSL	h							10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
Pump Station		Upgrade pumpstation	No.	m^3		2,616	79	2004	2004	1		0.0	2,616.4	0.0	2,616.4
Infrastructure															
Infrastructure															
Advance Infr															
Advance Infr											10.0%	0	0	0	0
Total					21,412	2,616	79								
					24,028										

Year	Cost Factors: Social & Environ.	Admin.
0	0.000	
1	0.000	
2	0.000	
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost (after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	0.25%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	40 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

DISSERTATION
Option Mandini / Tugela Transfer   Analysis Period 40 years

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	12,847	0	0	12,847	0	0	12,847	0	0	12,847	0	0	12,847	0	0
2004	11,181	0	0	11,181	0	0	10,548	0	0	10,353	0	0	10,165	0	0
2005	0	158	20	0	158	20	0	141	18	0	136	17	0	131	17
2006	0	158	21	0	158	21	0	133	18	0	126	17	0	119	16
2007	0	158	22	0	158	22	0	125	17	0	116	16	0	108	15
2008	0	158	23	0	158	23	0	118	17	0	108	15	0	98	14
2009	0	158	24	0	158	24	0	112	17	0	100	15	0	89	13
2010	0	158	24	0	158	24	0	105	16	0	92	14	0	81	13
2011	0	158	25	0	158	25	0	99	16	0	85	14	0	74	12
2012	0	158	26	0	158	26	0	94	16	0	79	13	0	67	11
2013	0	158	27	0	158	27	0	88	15	0	73	13	0	61	10
2014	0	158	28	0	158	28	0	83	15	0	68	12	0	55	10
2015	0	158	29	0	158	29	0	79	14	0	63	12	0	50	9
2016	0	158	30	0	158	30	0	74	14	0	58	11	0	46	9
2017	0	158	31	0	158	31	0	70	14	0	54	11	0	42	8
2018	0	158	32	0	158	32	0	66	13	0	50	10	0	38	8
2019	0	551	33	0	551	33	0	217	13	0	161	10	0	120	7
2020	0	158	34	0	158	34	0	59	13	0	43	9	0	31	7
2021	0	158	35	0	158	35	0	55	12	0	40	9	0	28	6
2022	0	158	36	0	158	36	0	52	12	0	37	8	0	26	6
2023	0	158	37	0	158	37	0	49	12	0	34	8	0	24	6
2024	0	158	38	0	158	38	0	47	11	0	31	8	0	21	5
2025	0	158	39	0	158	39	0	44	11	0	29	7	0	19	5
2026	0	158	40	0	158	40	0	41	11	0	27	7	0	18	5
2027	0	158	41	0	158	41	0	39	10	0	25	7	0	16	4
2028	0	158	43	0	158	43	0	37	10	0	23	6	0	15	4
2029	0	158	44	0	158	44	0	35	10	0	21	6	0	13	4
2030	0	158	45	0	158	45	0	33	9	0	20	6	0	12	3
2031	0	158	46	0	158	46	0	31	9	0	18	5	0	11	3
2032	0	158	47	0	158	47	0	29	9	0	17	5	0	10	3
2033	0	158	49	0	158	49	0	28	8	0	16	5	0	9	3
2034	0	551	50	0	551	50	0	90	8	0	51	5	0	29	3
2035	0	158	51	0	158	51	0	25	8	0	13	4	0	7	2
2036	0	158	52	0	158	52	0	23	8	0	12	4	0	7	2
2037	0	158	54	0	158	54	0	22	7	0	12	4	0	6	2
2038	0	158	55	0	158	55	0	21	7	0	11	4	0	6	2
2039	0	158	56	0	158	56	0	19	7	0	10	4	0	5	2
2040	0	158	58	0	158	58	0	18	7	0	9	3	0	5	2
2041	0	158	59	0	158	59	0	17	6	0	8	3	0	4	2
2042	0	158	60	0	158	60	0	16	6	0	8	3	0	4	1
2043	0	158	62	0	158	62	0	15	6	0	7	3	0	3	1
2044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	24,028	6,954	1,528	24,028	6,954	1,528	23,395	2,450	450	23,200	1,890	331	23,012	1,509	254

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	26,295	3.3	787
8%	25,422	2.5	1007
10%	24,775	2.0	1242

Commission date 2004

Transfer capacity (m^3/s) 0.017

Check: 24,028

Project Name	DISSERTATION	File Name	ECO_01M.xls
Option	NCSS to Zinkwazi	Date	01-Jul-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.012

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap											
Waterworks											10.0%	0	0	0	0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline		NCSS to Zinkwazi	400.00	22000.00	27,487	0		2003	2004	2	20.0%	16,492.1	0.0	10,994.7	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station											10.0%	0	0	0	0
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					27,487	0	0								
					27,487										

Year	Cost Factors	
	Social & Environ.	Admin.
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	0.25%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	20 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

DISSERTATION

NCSS to Zinkwazi **Analysis Period 20 years**

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	16,492	0.0	0	16,492	0	0	16,492	0	0	16,492	0	0	16,492	0	0
2004	10,995	0.0	0	10,995	0	0	10,372	0	0	10,180	0	0	9,995	0	0
2005	0	68.7	0	0	69	0	0	61	0	0	59	0	0	57	0
2006	0	68.7	0	0	69	0	0	58	0	0	55	0	0	52	0
2007	0	68.7	0	0	69	0	0	54	0	0	51	0	0	47	0
2008	0	68.7	0	0	69	0	0	51	0	0	47	0	0	43	0
2009	0	68.7	0	0	69	0	0	48	0	0	43	0	0	39	0
2010	0	68.7	0	0	69	0	0	46	0	0	40	0	0	35	0
2011	0	68.7	0	0	69	0	0	43	0	0	37	0	0	32	0
2012	0	68.7	0	0	69	0	0	41	0	0	34	0	0	29	0
2013	0	68.7	0	0	69	0	0	38	0	0	32	0	0	26	0
2014	0	68.7	0	0	69	0	0	36	0	0	29	0	0	24	0
2015	0	68.7	0	0	69	0	0	34	0	0	27	0	0	22	0
2016	0	68.7	0	0	69	0	0	32	0	0	25	0	0	20	0
2017	0	68.7	0	0	69	0	0	30	0	0	23	0	0	18	0
2018	0	68.7	0	0	69	0	0	29	0	0	22	0	0	16	0
2019	0	68.7	0	0	69	0	0	27	0	0	20	0	0	15	0
2020	0	68.7	0	0	69	0	0	26	0	0	19	0	0	14	0
2021	0	68.7	0	0	69	0	0	24	0	0	17	0	0	12	0
2022	0	68.7	0	0	69	0	0	23	0	0	16	0	0	11	0
2023	**0**	**68.7**	**0**	**0**	**69**	**0**	**0**	**21**	**0**	**0**	**15**	**0**	**0**	**10**	**0**
2024	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2025	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2033	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2034	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2044	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**27,487**	**1,306**	**0**	**27,487**	**1,306**	**0**	**26,864**	**723**	**0**	**26,672**	**611**	**0**	**26,487**	**523**	**0**

Commission date 2004

Transfer capacity (m^3/s) 0.01

Check: 27,487

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	27,588	2.2	1263
8%	27,283	1.9	1472
10%	27,010	1.6	1692

Project Name	DISSERTATION	File Name	ECO_01M.xls
Option	NCSS to Zinkwazi	Date	01-Jan-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.012

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks											10.0%	0	0	0	0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline		NCSS to Zinkwazi	400.00	22000.00	27,487	0		2003	2004	2	20.0%	16,492.1	0.0	10,994.7	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station											10.0%	0	0	0	0
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					27,487	0	0								
					27,487										

Year	Cost Factors: Social & Environ.	Cost Factors: Admin.
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	0.25%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	30 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

DISSERTATION

NCSS to Zinkwazi   Analysis Period 30 years

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	16,492	0.0	0	16,492	0	0	16,492	0	0	16,492	0	0	16,492	0	0
2004	10,995	0.0	0	10,995	0	0	10,372	0	0	10,180	0	0	9,995	0	0
2005	0	68.7	0	0	69	0	0	61	0	0	59	0	0	57	0
2006	0	68.7	0	0	69	0	0	58	0	0	55	0	0	52	0
2007	0	68.7	0	0	69	0	0	54	0	0	51	0	0	47	0
2008	0	68.7	0	0	69	0	0	51	0	0	47	0	0	43	0
2009	0	68.7	0	0	69	0	0	48	0	0	43	0	0	39	0
2010	0	68.7	0	0	69	0	0	46	0	0	40	0	0	35	0
2011	0	68.7	0	0	69	0	0	43	0	0	37	0	0	32	0
2012	0	68.7	0	0	69	0	0	41	0	0	34	0	0	29	0
2013	0	68.7	0	0	69	0	0	38	0	0	32	0	0	26	0
2014	0	68.7	0	0	69	0	0	36	0	0	29	0	0	24	0
2015	0	68.7	0	0	69	0	0	34	0	0	27	0	0	22	0
2016	0	68.7	0	0	69	0	0	32	0	0	25	0	0	20	0
2017	0	68.7	0	0	69	0	0	30	0	0	23	0	0	18	0
2018	0	68.7	0	0	69	0	0	29	0	0	22	0	0	16	0
2019	0	68.7	0	0	69	0	0	27	0	0	20	0	0	15	0
2020	0	68.7	0	0	69	0	0	26	0	0	19	0	0	14	0
2021	0	68.7	0	0	69	0	0	24	0	0	17	0	0	12	0
2022	0	68.7	0	0	69	0	0	23	0	0	16	0	0	11	0
2023	**0**	**68.7**	**0**	**0**	**69**	**0**	**0**	**21**	**0**	**0**	**15**	**0**	**0**	**10**	**0**
2024	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2025	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2033	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2034	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2035	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2036	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2044	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	27,487	1,306	0	27,487	1,306	0	26,864	723	0	26,672	611	0	26,487	523	0

Discount Rate	Present worth of costs @ R1,00/m^3	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	27,588	2.9	965
8%	27,283	2.3	1200
10%	27,010	1.9	1451

Commission date   2004

Transfer capacity (m^3/s)   0.01

Check: 27,487

Project Name	DISSERTATION	File Name	ECO_01M.xls
Option	NCSS to Zinkwazi	Date	01-Jan-03
Base Year	2003	Component Life	30

Phase	1	Commission Year	2004	Output (m^3/s)	0.012

Element	Type	Name	Characteristics		Capital Costs		Electricity Costs per year	Timing			Construction Cash Flow				
					Civil	Mech. & Elec.		Start	End	Duration	1st year %	Year 1		Annual	
												Civil	M&E	Civil	M&E
				Cap.											
Waterworks											10.0%	0	0	0	0
			Dia.	Length											
Tunnel											20.0%	0	0	0	0
			Dia.	Length											
Pipeline		NCSS to Zinkwazi	400.00	22000.00	27,487	0		2003	2004	2	20.0%	16,492.1	0.0	10,994.7	0.0
			FSL	h											
Dam											10.0%	0	0	0	0
Dam											10.0%	0	0	0	0
			No.	m^3											
Pump Station											10.0%	0	0	0	0
Infrastructure															
Infrastructure															
Advance Infr											10.0%	0	0	0	0
Advance Infr															
Total					27,487	0	0								
					27,487										

Year	Cost Factors	
	Social & Environ.	Admin.
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
Total	0.000	0

Other Costs

Description	Cost
Social & Environ.	0
Administration	

Maintenance as % of Construction Cost
(after Commissioning)

ANNUAL	Civil	Mech & Elec
Waterworks	0.25%	4.00%
Tunnel	0.10%	4.00%
Pipeline	0.25%	4.00%
Dam	0.25%	4.00%
Pump Station	0.25%	4.00%
Other	0.25%	4.00%
PERIODIC	Period (yrs)	%
Pump Station (M&E)	15.0	15.00%

Sensitivity

		Comm Date
Original		
Sensitivity	40 years	
Sensitised		

Engineering as % of Construction Cost

Pre-Engineering	0.00%
Construction	0.00%

Discount Rates

Low	6%
Medium	8%
High	10%

Note: 1st year's costs are not discounted

DISSERTATION

NCSS to Zinkwazi **Analysis Period 40 years**

Year	Phase 1			Total Annual Cost			NPV Cost (1994) @ 6%			NPV Cost (1994) @ 8%			NPV Cost (1994) @ 10%		
	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity	Capital	Operation & Maintenance	Electricity
Shadow	1	1	1	1	1	1									
2003	16,492	0.0	0	16,492	0	0	16,492	0	0	16,492	0	0	16,492	0	0
2004	10,995	0.0	0	10,995	0	0	10,372	0	0	10,180	0	0	9,995	0	0
2005	0	68.7	0	0	69	0	0	61	0	0	59	0	0	57	0
2006	0	68.7	0	0	69	0	0	58	0	0	55	0	0	52	0
2007	0	68.7	0	0	69	0	0	54	0	0	51	0	0	47	0
2008	0	68.7	0	0	69	0	0	51	0	0	47	0	0	43	0
2009	0	68.7	0	0	69	0	0	48	0	0	43	0	0	39	0
2010	0	68.7	0	0	69	0	0	46	0	0	40	0	0	35	0
2011	0	68.7	0	0	69	0	0	43	0	0	37	0	0	32	0
2012	0	68.7	0	0	69	0	0	41	0	0	34	0	0	29	0
2013	0	68.7	0	0	69	0	0	38	0	0	32	0	0	26	0
2014	0	68.7	0	0	69	0	0	36	0	0	29	0	0	24	0
2015	0	68.7	0	0	69	0	0	34	0	0	27	0	0	22	0
2016	0	68.7	0	0	69	0	0	32	0	0	25	0	0	20	0
2017	0	68.7	0	0	69	0	0	30	0	0	23	0	0	18	0
2018	0	68.7	0	0	69	0	0	29	0	0	22	0	0	16	0
2019	0	68.7	0	0	69	0	0	27	0	0	20	0	0	15	0
2020	0	68.7	0	0	69	0	0	26	0	0	19	0	0	14	0
2021	0	68.7	0	0	69	0	0	24	0	0	17	0	0	12	0
2022	0	68.7	0	0	69	0	0	23	0	0	16	0	0	11	0
2023	0	68.7	0	0	69	0	0	21	0	0	15	0	0	10	0
2024	0	68.7	0	0	69	0	0	20	0	0	14	0	0	9	0
2025	0	68.7	0	0	69	0	0	19	0	0	13	0	0	8	0
2026	0	68.7	0	0	69	0	0	18	0	0	12	0	0	8	0
2027	0	68.7	0	0	69	0	0	17	0	0	11	0	0	7	0
2028	0	68.7	0	0	69	0	0	16	0	0	10	0	0	6	0
2029	0	68.7	0	0	69	0	0	15	0	0	9	0	0	6	0
2030	0	68.7	0	0	69	0	0	14	0	0	9	0	0	5	0
2031	0	68.7	0	0	69	0	0	13	0	0	8	0	0	5	0
2032	0	68.7	0	0	69	0	0	13	0	0	7	0	0	4	0
2033	0	68.7	0	0	69	0	0	12	0	0	7	0	0	4	0
2034	0	68.7	0	0	69	0	0	11	0	0	6	0	0	4	0
2035	0	68.7	0	0	69	0	0	11	0	0	6	0	0	3	0
2036	0	68.7	0	0	69	0	0	10	0	0	5	0	0	3	0
2037	0	68.7	0	0	69	0	0	9	0	0	5	0	0	3	0
2038	0	68.7	0	0	69	0	0	9	0	0	5	0	0	2	0
2039	0	68.7	0	0	69	0	0	8	0	0	4	0	0	2	0
2040	0	68.7	0	0	69	0	0	8	0	0	4	0	0	2	0
2041	0	68.7	0	0	69	0	0	8	0	0	4	0	0	2	0
2042	0	68.7	0	0	69	0	0	7	0	0	3	0	0	2	0
2043	0	68.7	0	0	69	0	0	7	0	0	3	0	0	2	0
2044	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2045	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2046	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2047	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2048	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2049	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2051	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2052	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2053	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2054	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2055	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2056	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2057	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2058	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2059	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	27,487	2,680	0	27,487	2,680	0	26,864	969	0	26,672	756	0	26,487	610	0

Discount Rate	Present worth of costs	NPV of Water Delivered @ R1,00/m^3	Unit Reference Value (cents/m^3)
6%	27,834	3.3	844
8%	27,428	2.5	1095
10%	27,097	2.0	1366

Commission date 2004

Transfer capacity (m^3/s) 0.01

Check: 27,487

ANNEXURE I

GLOSSARY

NTU (Nephelometric Turbidity Units) – Turbidity, defined scientifically as the light-scattering ability of water, is a measure of the cloudiness or muddiness of water.

TDS (Total Dissolved Salts) – Electrical conductivity (EC) is a measurement of the ease with which water conducts electricity. Distilled water conducts electricity poorly, while seawater, with its very high salt content, is a very good conductor of electricity. The EC of the water indicates what the total dissolved salt (TDS) content of the water is. The EC measurement in mS/m can be used to estimate the TDS in mg/l by multiplying the EC by the factor 6.5 i.e. TDS = EC x 6.5. The EC indicates whether the water is fresh or salty.

TRANSMISSIVITY - Transmissivity can be defined as the rate at which water is transferred through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the hydraulic conductivity and the thickness of the saturated portion of an aquifer.

SDI (Silt Density Index) – The SDI is an empirical test used to characterize the fouling potential of a feedwater stream. The test is based on measuring the rate of plugging a 45 micron filter using a constant 30 psig feed pressure for specified period of time. SDI15 refers to a silt density index test, which was run for 15 minutes. Typically spiral wound systems require an SDI < 5 and hollow fibre systems require an SDI < 3. Most deep well waters have an SDI of 3 and most surface water have SDI's greater than 6.

STORATIVITY - The Storativity (S) of a confined aquifer is defined as the product of its specific storage (S_s) and its saturated thickness (b).