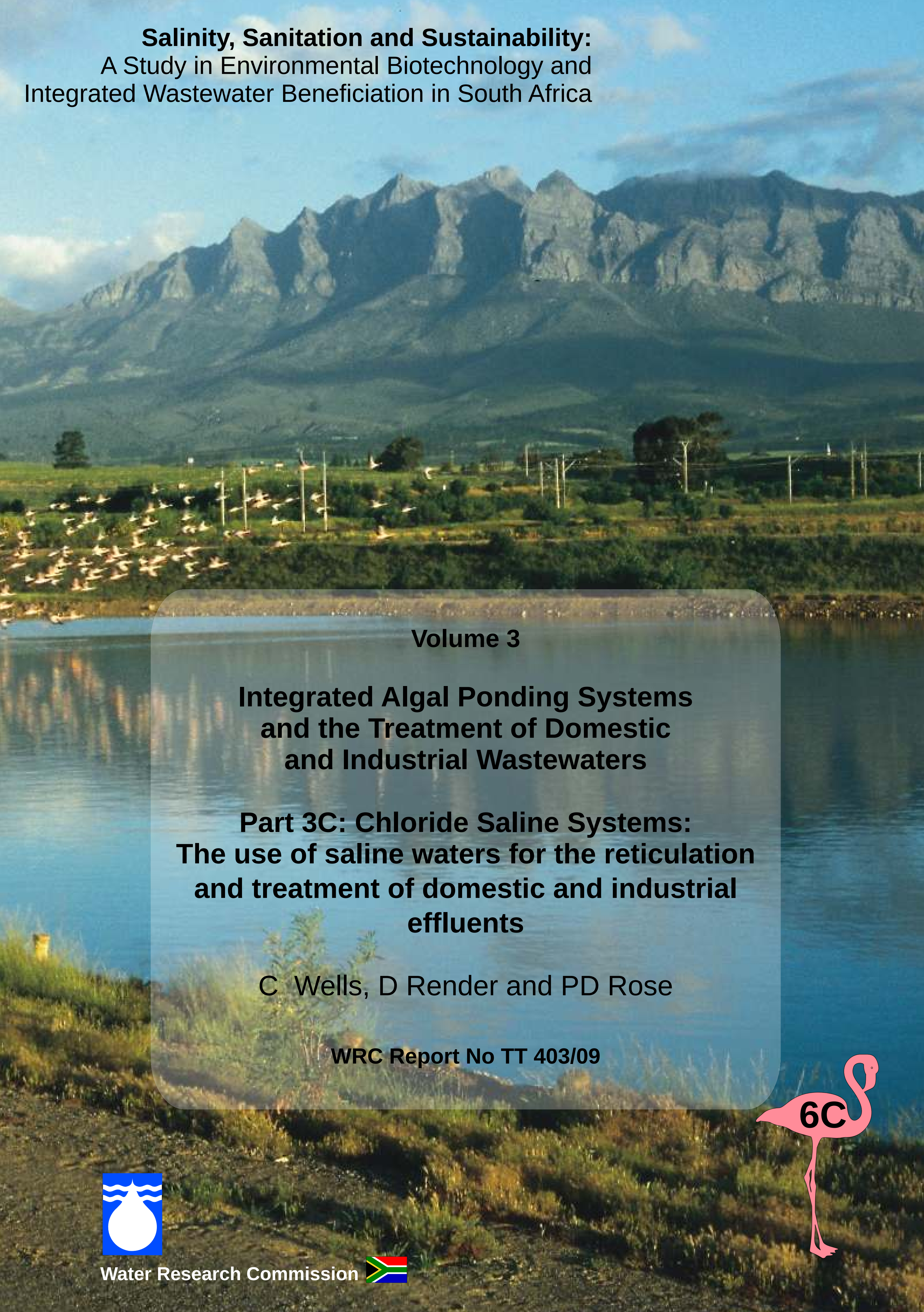

Salinity, Sanitation and Sustainability:
A Study in Environmental Biotechnology and
Integrated Wastewater Beneficiation in South Africa

Volume 3

Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters

Part 3C: Chloride Saline Systems: The use of saline waters for the reticulation and treatment of domestic and industrial effluents

C Wells, D Render and PD Rose

WRC Report No TT 403/09

6C

Water Research Commission

REPORTS in the WATER RESEARCH COMMISSION PROJECT SERIES

SALINITY, SANITATION and SUSTAINABILITY
A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa

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Part 1: Meso-Saline Wastewaters
The *Spirulina* Model

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Report 4: Volume 3 - Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters

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SALINITY, SANITATION and SUSTAINABILITY
Biotechnology of Saline and Sewage Wastewater

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Cover Photograph:

Flamingoes on tannery wastewater ponds at Mossop Western Leathers Co., Wellington, South Africa. The presence of Phoenicopteridae, including both the Greater and Lesser Flamingo, is an important indicator of healthy and naturally functioning saline aquatic ecosystems. This flock occupied the ponding system shortly after commissioning the novel *Spirulina*-based Integrated Algal Ponding System which had been developed for the treatment of tannery wastewaters. This apparent seal of environmental approval became an icon for the studies which followed in this series.

Photograph by Roger Rowswell, whose observation of this system, over a number of years, was instrumental in the initiation of these studies.

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa

Volume 3

INTEGRATED ALGAL PONDING SYSTEMS AND THE TREATMENT OF DOMESTIC AND INDUSTRIAL WASTEWATERS

Part 3C: Chloride Saline Systems: The use of saline waters for the reticulation and treatment of domestic and industrial effluents

Report to the
Water Research Commission on

By

C Wells, D Render and PD Rose

on behalf of

Environmental Biotechnology Research Unit,
Rhodes University
Grahamstown

WRC Report No. TT 403/09

APRIL 2009

Obtainable from:

Water Research Commission
Private Bag X03
Gezina
0031

Report to the Water Research Commission on Project K5/1621, 'Development of sustainable low-cost management for saline sewage and saline mine drainage wastewaters using integrated algal ponding systems.' Aspects of this project concerning the use of saline wastewaters for the reticulation and treatment of sewage wastes have been reported together with WRC Project K5/1456.

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PREFACE

The threat of rising salinity to the public water system in South Africa has been a cause of concern for many years and was a motivating factor in the establishment and early development of the Water Research Commission (WRC) in the 1970s. Since then the WRC has made a substantial investment in expanding an understanding of the nature of the problem and in the development of innovative remedial responses to it.

The investigation of a biotechnology-based response to the problem led to a research programme on saline wastewaters undertaken, over a 20 year period, by the Environmental Biotechnology Research Unit (EBRU) at Rhodes University. These findings have been published by the WRC in the series "Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa" – also known informally as the 'Flamingo Series'. A number of recommendations for follow-up actions emerged from these studies and included further development of the long-range sustainability potential available in linking the management of saline and sewage wastewaters in co-treatment operations.

A number of WRC follow-up studies have targeted aspects of these recommendations including the development of biological sulphide oxidation systems for the production of elemental sulphur from treated saline mine minewaters, the mathematical modeling of biological sulphate reducing systems (a major collaborative study led by University of Cape Town Civil Engineering Department), and the recovery and reuse of treated minewaters in agricultural production and thereby establishing conditions for sustainable economic, environmental and social mine closure. Among several other outcomes, the approach led to the development of the Rhodes BioSURE® Process which links the disposal of sewage sludges, and other complex organic wastes, in the treatment of saline acidic mine drainage wastewaters.

Two further follow-up recommendations of the "Salinity, Sanitation and Sustainability" study were tackled in Project K5/1621 and are dealt with in the current two-volume report series titled "Biotechnology of Saline Wastewater Treatment". Volume 1 (Flamingo 6: Part 3B) deals with further studies on the development of the WRC patented ASPAM Process which utilizes Integrated Algal Ponding Systems in the treatment of sulphate salinity, acidity and heavy metal contamination in mine drainage wastewaters. The initial work on this process had been detailed in WRC Report TT 192/02 (Volume 6 in the Flamingo Series). Volume 2 (Flamingo 6: Part 3C) reports a preliminary investigation on the practical use of chloride saline wastewaters for the reticulation and treatment of domestic and industrial effluents. Aspects of the saline water reticulation study were also investigated in WRC Project K5/1456 and these findings are reported together in the Volume 2 report.

EXECUTIVE SUMMARY

INTRODUCTION

This report forms Volume 2 of a wider study on the biotechnology of saline wastewater treatment that has also investigated various aspects of mine water salinity (Volume 1). Both saline wastewaters and inadequately treated sewage present major threats to the sustainability of the national water resource in South Africa and the ability to deal with the problem is, in an important measure, technologically dependent. Apart from the ability to deal with these problems, the capacity to do so is also central to solutions which are sustainable over the long term.

These studies have been underpinned by the concepts of Integrated Wastewater Management in which co-treatment would allow the recovery of products of value from the wastewater treatment operation. This provides an economic basis to sustainable development and in this regard "Triple Bottom Line" economics are targeted, including social, economic and environmental interests.

This part of the wider study has investigated the use of saline waters for the reticulation and treatment of domestic and industrial effluents. Not only does this have the potential to relieve pressure on the fresh water resource but also provides a useful function for saline wastes in an application where the potability of the water is not an essential requirement.

AIMS

The aims of the study were to investigate the economic, social, technical and technological feasibility of treating sewage reticulated in saline water, including nutrient removal and disinfection, for urban and rural communities. This was known as the "Saline Sewage Treatment" component of the study and included a literature review and survey of current practice, a feasibility assessment of the saline sewage option and a preliminary evaluation of the potential of Integrated Algal Ponding Systems (IAPS) technology for the treatment of sewage in saline waters.

REVIEW

A literature review has been presented which reports on both experimental investigations and full-scale applications of saline sewage treatment systems. While some practical applications have been considered, the economics and problems associated with corrosion and dual pipeline systems have presented constraints. In terms of biological treatment it has been shown that saline adapted cultures are required for effective operation rather than the acclimation of fresh water microbial inocula. Although sea water has been used for the reticulation of sewage around the world, few large-scale examples are available where the resultant saline effluent is treated before discharge back to a marine outfall.

FEASIBILITY

A feasibility assessment of the saline sewage co-treatment option has been undertaken and has reported on the application of the concept, and outlined economic and technical considerations impacting on its development.

INTEGRATED ALGAL PONDING SYSTEMS

Given apparent technological constraints, as one of the factors limiting development of the saline sewage co-treatment concept, the project has undertaken an evaluation of an application of Integrated Algal Ponding Systems (IAPS) for the treatment of saline sewage wastewaters.

Laboratory studies were undertaken to isolate, enrich and develop saline adapted cultures for saline sewage treatment. A pilot plant was constructed at the Rhodes University Environmental Biotechnology Research Unit (EBRU) field station in Grahamstown (Figure 1&2) in order to subject the concept of the IAPS application to preliminary evaluation.

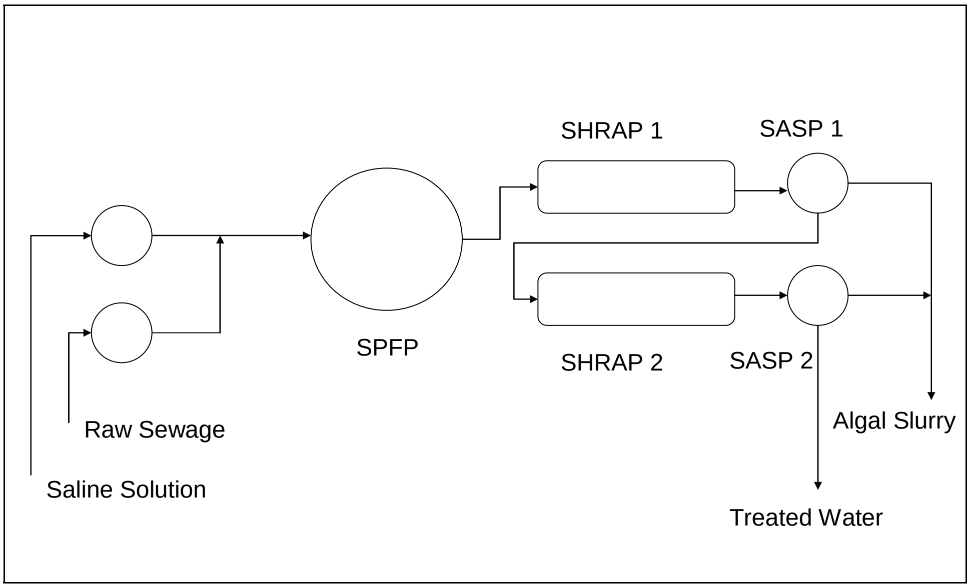

Figure ES1 Plan diagram of the Integrated Algal Ponding Systems pilot plant constructed at the EBRU Field Station in Grahamstown. Raw sewage was blended into the saline solution in order to simulate the reticulation of sewage in a saline stream. (SPFP = saline primary facultative pond; SHRAP = saline high rate algal pond; SASP = saline algal settling pond).

Figure ES2 The saline IAPS pilot plant installation located at the EBRU campus, Grahamstown.

In this system a synthetic saline sewage feed make-up was used where raw sewage and a NaCl saline concentrate were blended just prior to feeding to the anaerobic pit of the Primary Facultative Pond. Thereafter the IAPS plant was operated conventionally as described elsewhere (Rose *et al*., 2002c). Following the construction and commissioning of the pilot plant, it was operated over a number of months to establish stable operating conditions. Thereafter, operating variables were recorded over a 10-month period for TOC, nitrogen and phosphate removal across the system. (TOC measurement was used here given chloride interference with COD analysis). Figures 3, 4 & 5 record the performance of the system for these parameters which compares favourably to the operation of a conventional fresh water IAPS system for which 9 years of operating data are available at the same site (Wells, 2005).

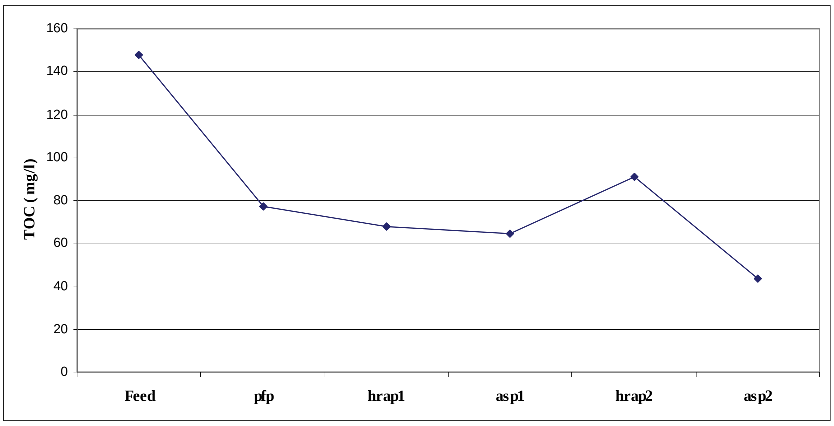

Figure ES3: Total Organic Carbon (TOC) removal across the saline integrated algal ponding system. (PFP = Primary Facultative Pond; HRAP = High Rate Algal Pond; ASP = Algal Settling Pond).

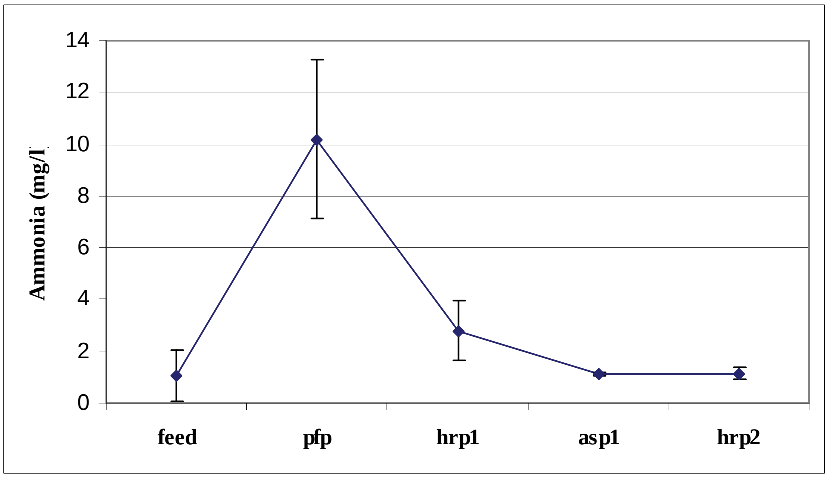

Figure ES4: Mean ammonia removal across the saline integrated algal ponding system over the nine month period June 2004 to March 2005. (PFP = Primary Facultative Pond; HRAP = High Rate Algal Pond; ASP = Algal Settling Pond).

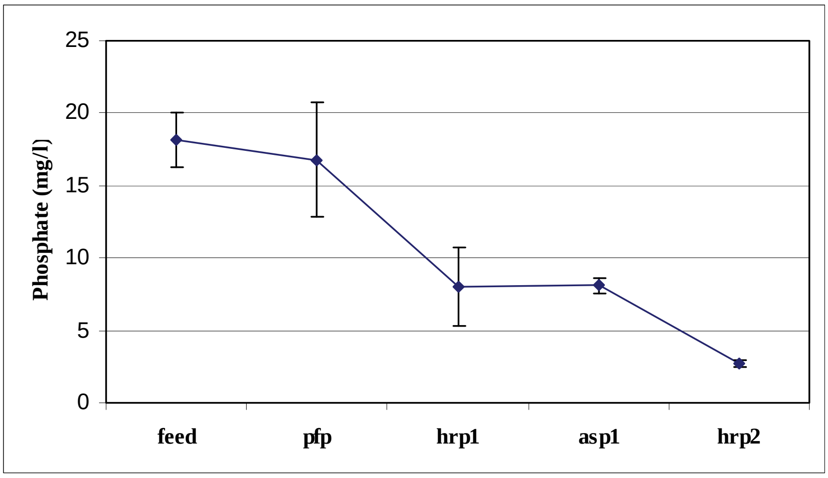

Figure ES5: Mean phosphate removal across the saline integrated algal ponding system over the nine month period June 2004-March 2005. (PFP = Primary Facultative Pond; HRAP = High Rate Algal Pond; ASP = Algal Settling Pond).

It was also shown that the disinfection function was comparable to values achieved in the fresh water Independent High Rate Algal Pond System (IHRAP) reported by Wells (2005). *E. coli* was reduced from approximately $9X10^7$ cfu/100 ml to <10 cfu/100 ml.

It was also reported that problems are encountered in the pumping and dosing of relatively small volumes of sewage in the pilot plant and that, although the study provided valuable indicators of system performance, accurate data required for the development of process design detail would need to be acquired on a larger technical-scale plant.

Based on these findings the following recommendations were made:

- While the literature survey produced a certain amount of information on the saline sewage concept, it was evident that more detailed insights would depend on contacts with saline sewage operations. These should be expanded and more detailed information acquired on the status of such systems than is currently reported in the literature.

- With the demonstration of preliminary feasibility of the IAPS saline sewage application, a detailed study of the economics of the saline sewage system should be undertaken to provide inputs necessary for policy decision making;

- The results of the study provide a provisional indication of the viability of the IAPS saline sewage system and that its performance would be expected to be comparable to that recorded for the equivalent freshwater system operated at the same site and treating the same wastewater. However, operation of the system at a small pilot scale imposes constraints on the interpretation of process and kinetic data and it is thus recommended that sufficient information has been acquired to proceed to an evaluation of the process application at larger scale. This would be required for deriving detailed design criteria in order to progress to full-scale engineering of the process application.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the Water Research Commission for finance and support throughout the project. They would also like to thank the Reference Committee for critical comment and constructive suggestions.

Dr H Snyman
Ms H Greben
Mrs W Moolman
Mrs B Nel
Mr H Joubert
Mr L du Preez
Mr J Harrison

LIST OF FIGURES

ABBREVIATIONS

AIWPS	Advanced Integrated Wastewater Ponding System
ASP	Algal Settling Pond
ASPAM	Algal Sulphate Reducing Ponding Process for Acidic Metal Wastewater Treatment
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DWAF	Department of Water Affairs and Forestry
EBG	Environmental Biotechnology Group
EBRU	Environmental Biotechnology Research Unit (Rhodes University)
GDW	Grahamstown Disposal Works
HRAP	High Rate Algal Pond
HRT	Hydraulic Retention Time
IAPS	Integrated Algal Ponding System
ICBA	International Centre for Biosaline Agriculture
MLSS	Mixed Liquor Suspended Solids
MUDS	Marine Underwater Depuration System
PFP	Primary Facultative Pond
RBC	Rotating Biodisc Contactor
SASP	Saline Algal Settling Pond
SHRAP	Saline High Rate Algal Pond
SPFP	Saline Primary facultative Pond
TDS	Total Dissolved Solids
TKN	Total Kjeldal Nitrogen
WRC	Water Research Commission
WSP	Waste Stabilisation Ponds

1 INTRODUCTION

This report forms Volume 2 of a wider study on the biotechnology of saline and sewage wastewater co-treatment that has also investigated various aspects of mine water salinity (Volume 1). Both saline wastewaters and inadequately treated sewage present major threats to the sustainability of the public water system in South Africa and the ability to deal with the problem is, in an important measure, technologically dependent. Apart from the ability to deal with these problems, the capacity to do so is also central to solutions which are sustainable over the long term.

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1.1 AIMS

The aims of the study were to investigate the economic, social, technical and technological feasibility of treating sewage reticulated in saline water, including nutrient removal and disinfection, for urban and rural communities. This was known as the "Saline Sewage Treatment" component of the study and included a literature review and survey of current practice, a feasibility assessment of the saline sewage option and a preliminary evaluation of the potential of Integrated Algal Ponding Systems (IAPS) technology for the treatment of sewage in saline waters.

2 A SURVEY OF CURRENT PRACTICE

2.1 LITERATURE REVIEW

2.1.1 Introduction

Mara and Feachem (2001) have noted that deficiencies in water supply, sanitation and hygiene are second only to malnutrition as the principal cause of death- and disability-adjusted years lost globally. They go on to claim that in 2000, 18% of the world population were without sufficient water supplies and about 40% were without adequate sanitation. Whilst figures indicate that an increasing number of people are receiving improved water supply and sanitation, due to population growth, the overall statistics are actually getting worse. The situation in Africa is even worse than indicated by these global figures, where morbidity and mortality (water related diseases kill an estimated 3 million Africans annually), due to lack of adequate safe water supplies and sanitation, are still very high (Rose, 2002a). It is estimated that around 21 million South Africans do not have adequate sanitation and approximately 45% of the rural population do not have a satisfactory water supply (Rose, 2002a). The South African Department of Water Affairs and Forestry (DWAF, 2002) recognise this in their management policy, where they state that improved access to water is necessary to "increase levels of health and general well being." They emphasise in their water quality management goal that while water resources need to be scientifically managed and conserved, they also need to meet the social and economic requirements of the country. The South African Water Act No. 36 of 1998 supports this goal by stipulating that future water resource developments should be environmentally sustainable and that a component of the natural flow of rivers should be reserved to ensure some level of ecological functioning (Hughes & Hannart, 2003). This challenge is exacerbated by the arid climate in South Africa. South Africa receives only half the average world rainfall. Due to high evaporation rates, only 8% of this rainfall is carried in the rivers, compared to the world mean of 31% (Van Zyl, 2003). The combined effect of the climate, rapid population growth and inefficient water infrastructure is increasing the pressure on the river ecosystems across the whole of Southern Africa.

Smith *et al*. (1996) points out that insufficient water supplies present a limit to development in poor, tropical, coastal areas, however, not all water is required to be of potable standard. For communities with large coastlines, seawater could provide a viable alternative as a medium for reticulation sewage. This is particularly pertinent in relatively small, island towns where sea water has been utilised with varying degrees of success, e.g. Majuro Atoll in the Marshall Islands, Tarawa Atoll in Kiribati as well as in Gibraltar (Stear *et al*., 1997). Burnett (1974) also describes the use of sea water for toilet flushing in the US Virgin Islands. Tang (2000) maintains that dual water supplies are not only an option for rural areas or small seaside villages but are becoming increasingly viable for large urban areas in coastal zones. He states that about three quarters of the population in Hong Kong are supplied with sea water for toilet flushing. South Africa has a coastline of almost 3 000km (Van Zyl, 2003), the use of sea water for sewage reticulation, therefore, seems an obvious area for further investigation.

In a survey conducted by Smith *et al*. (1996) a number of areas of concern were noted that arise with the dual water supply system. These include corrosion of sewerage and equipment, cost of infrastructure and the technological constraints in treating saline sewage. These additional costs, over and above those related to fresh water treatment systems, would have to be offset against the severity of water shortages and the environmental and socio-economic benefits that accrued in a dual reticulation system. Also whether the project is "greenfield" or not would have a large influence on the cost. Installing a dual system from scratch would clearly be far more attractive than re-plumbing an existing sewage network (Smith *et al*., 1996). Corrosion can fairly easily be minimised by using suitable materials and, in fact, most of the materials routinely used for water supply and sewage, such as polyethylene or polyvinyl chloride (PVC) pipes and fittings are unaffected by both seawater and possible sulphuric acid produced by increased sulphate reduction (Smith *et al*., 1996). However, the effect of salt concentrations on treatment processes remains as a substantial and justified concern in the implementation of saline sewage systems. Some of the relevant literature on this subject will, thus, be discussed in this review.

2.1.2 The Biocatalyst: Source of Inoculum

Salt concentrations greater than 1% cause disintegration of cells due to loss of cellular water (plasmolysis) resulting in loss of microbial activity (Kargi & Uygur, 1995 and Woolard &

Irvine, 1994). Ludzack and Noran (1965) also report that high salinities can reduce the numbers of protozoa and filamentous organisms in activated sludge, which causes sludge bulking problems in effective sedimentation. According to Kincannon and Gaudy (1966) sludges acclimated to high salt concentrations indicate the selection and growth of new species rather than a biochemical acclimation of prevailing species. Utilising salt tolerant organisms in biological treatment systems should, therefore, alleviate these problems and provide for more successful treatment.

As salinity in an environment increases, the general trend is for species diversity to decrease, however, there are still many micro-fauna and -flora that are tolerant of saline conditions. Diatoms, filamentous green algae, sea grass, cyanobacteria as well as photosynthetic and heterotrophic bacteria flourish. Larger heterotrophs such as protozoa and branchiopods are also common (Borowitzka, 1981; Jones *et al*., 1981; Williams, 1981). A number of authors (Post, 1977; Javor, 1984; Mathrani & Boone, 1985; Paterek & Smith, 1985) have noted that some organisms such as brine shrimp (*Artemia salina*) and the halophilic bacteria (genera *Halobacterium*, *Halococcus* and *Haloarcula*) may even thrive in extremely saline brines. Mathrani and Boone (1985), and Paterek and Smith (1985) have also isolated halophilic methanogens from a solar saltern and the Great Salt Lake respectively. Halotolerant bacteria have been recorded in Antarctic saline lakes (McMeekin *et al.,* 1993).

According to Ollivier *et al*. (1994) there are also a number of sources of organic matter in hypersaline ecosystems; “Cyanobacteria and members of the Halobacteriaceae at high salt concentrations may add substantial quantities of organic matter from decomposition of their cell walls, which are composed of sugars, proteins and lipids.” They also note that invertebrates such as brine shrimp and brine fly as well as algae and plants growing nearby may contribute organic matter into the hypersaline system. Ollivier *et al.* (1994) also refer to the fact that where sulphate is not limiting, sulphate-reducing bacteria (SRB) may out-compete methanogens for these energy sources. This has been observed in marine environments; however, they feel that methanogenesis stops contributing to the mineralization of carbohydrates only once the NaCl concentration rises above 15%. From the evidence above, solar salterns or salt lakes should provide a range of organisms which would be suitable inocula for use in the treatment of saline sewage.

Other organically rich, saline environments that could, potentially, provide the adapted organisms for inoculating treatment systems are estuaries and mangroves. Mangroves, composed of tropical or subtropical plants inhabiting estuaries and tidal low lands, are frequently exposed to varying degrees of salinity. Micro-organisms in mangrove soils should, therefore, be fairly tolerant of salt (Ando *et al*., 2001). In addition to the salinity of these areas, they are also often areas where organic matter collects. Detritus and, in more modern times, anthropogenic wastes are washed down by rivers and, because of the often reduced exchange of water with the open sea, these contaminants accumulate (Ando *et al*., 2001, Tam *et al*., 2002). Alongi *et al.* (2001) found that approximately 60% of total organic carbon input into mangrove forests is retained in the sediment. Some mangroves studied in Thailand also appear to be phosphorous sinks (Holmboe *et al*., 2001). In a study conducted by Ando *et al*. (2001), they found that samples treated with inoculum from a Japanese mangrove had a CO_2 evolution rate that was twice that of the fresh water control, indicating that the microorganisms taken from the mangrove soil were effective in digesting the organic compounds. Other studies indicate that mangrove soils have a high denitrification potential (Tam, 1998; Bauza *et al*., 2002). Investigations by Tam *et al*. (2001, 2002) also show that microorganisms from estuaries and mangrove forests have evolved and developed abilities to utilise organic compounds such as polycyclic aromatic hydrocarbons (PAHs) and other petroleum-related hydrocarbons.

2.1.3 Saline Sewage Treatment Processes – Experimental Studies

The most common studies encountered in the literature refer to the effects of salinity on various forms of activated sludge treatment. Research into the effect of salt on conventional waste water treatment, i.e. activated sludge and anaerobic digestion, seems to have begun in earnest in the 1960s (Stewart *et al*., 1962; Ludzack & Noran, 1965; Kincannon & Gaudy, 1966 & 1968). Ludzack and Noran (1965) found that at chloride concentrations below 5 000 mg/l there were no detectable changes in sustained performance of activated sludge although, as mentioned previously, they did encounter problems with sedimentation and thus clarification. Nitrification, at high chloride levels was only about 10% of that for the same operation at low chloride concentrations. They also found that anaerobic digestion was far more sensitive to chlorides than activated sludge. In both processes chloride effects on digestion were greater at higher organic loadings. At NaCl concentrations up to 20 000 mg/l they encountered higher effluent solids and a decrease in the efficiency of oxygen demand removal of the wastes being treated. In the study carried out by Stewart *et al.* (1962), to check the application of biological treatment of shipboard wastes, it was demonstrated that it is feasible to use an aerobic biological process to treat wastewater under conditions of varying salinity. Under severe salinity changes (up to 100% seawater) or heavy organic and hydraulic loadings, temporary reductions in treatment efficiency did occur. The length of the recovery period depended on the duration and severity of the loadings.

Kincannon and Gaudy (1968) used a continuous flow-activated sludge plant to test the performance of activated sludge exposed to increasing concentrations of NaCl. They established that the sludge was able to attain excellent removal of the chemical oxygen demand (COD) at salinities up to 30 000 mg/l after a relatively short acclimation period of about 30 hours. These results were, however, obtained with a gradual increase in salt load; shock additions of NaCl resulted in very poor substrate removal in the sludge and a much longer recovery time. Interestingly, operating the reactor at 8 000 mg/l NaCl resulted in a 75% increase in sludge yield. They believe this could be due to an overall increase in yield of all cells, a change in predominant species or a combination of both. Whatever the reason, this finding has fairly major design implications as sludge handling facilities in a full scale plant would have to be sized accordingly. Kincannon and Gaudy (1966) also conducted studies using batch activated sludge units that showed a 30% decrease in COD removal efficiency at slug doses of 30 000 mg/l NaCl. At 45 000 mg/l NaCl there was a severe impairment in substrate removal efficiency. Another finding made in this study was that sludges developed in high salt concentrations were more drastically affected by a rapid change to fresh water than vice versa. This is an observation that has subsequently been supported by numerous other investigations and is apparently a result of extensive cell lysis, which can cause an increase in COD due to the release of cell constituents (Lawton & Eggert, 1957; Burnett 1974; Kincannon & Gaudy, 1966, 1968). Kargi and Dincer (1996) also found that that the COD removal rate dropped significantly with increasing salinity in a fed batch reactor inoculated with *Zooglea ramigera*, although they still achieved nearly 60% COD removal at 50 000 mg/l salt concentration. In addition, their experiments showed a 29% reduction in COD removal rate at 50 000 mg/l, indicating that a longer hydraulic retention time may be necessary in such systems operated at higher salinities.

The effect of microbial culture type and salt content on the biological treatment of waste water was investigated by Kargi and Uygur (1995), using an aerated percolator column reactor and a synthetic waste water, with molasses as the carbon source. After establishing that a mixed culture of activated sludge and the halophilic bacteria, *Halobacter halobium*, gave the best results in terms of COD removal at 10 000 mg/l NaCl, they proceeded to check the effect of different salinities on the COD removal rate and efficiency. With increases of up to 20 000 mg/l NaCl there was no significant decrease in performance and a COD removal rate of 90% was achieved. The mixed culture performance was adversely affected at 30 000 mg/l (roughly sea water) and then improved again at above 40 000 mg/L. The conclusion drawn from this work was that at concentrations of 30 000 mg/l, activity of the activated sludge is decreased and yet the salinity is not yet high enough for the *Halobacter* to thrive.

Woolard and Irvine (1994) showed that a biofilm of halophiles, isolated from the Great Salt Lake, was able to remove more than 99% of phenol from a synthetic waste containing 150 000 mg/l salt. They used a sequencing batch biofilm reactor, where oxygen is supplied to the system by diffusion through silicon tubing, which also provides a surface for the formation of the biofilm that degrades waste organics. In a similar experiment, using the same Great Salt Lake Halophiles, but in this case a conventional sequencing batch reactor (i.e. without the biofilm), an average 99.5% phenol removal was achieved over a period of seven months in150 000 mg/l salt (Woolard & Irvine, 1994). Peyton *et al.* (2002) confirmed the phenol biodegradation capability of halophilic bacteria, isolated from three different locations, i.e. Great Salt Lake basin in Utah, Cargill Solar Salt Plant in California and the Soap Lake region in Washington.

The studies mentioned thus far have focused on the removal of COD, by activated sludge from saline waste waters. Intrasungkha *et al.* (1999), however, focused on biological nutrient removal in a sequencing batch reactor fed with artificial seafood processing wastewater. At salinities as low as 5 000 mg/l nutrient removal was retarded and in particular, phosphorus removal was very poor. Abu-ghararah and Sherrard (1993) also reported very poor phosphorus removal from their activated sludge unit at 4 000 mg/l NaCl, although nitrogen and COD removal efficiency was the same for non-saline wastewater. Campos *et al.* (2002) worked on the removal of nutrients, specifically ammonia, from saline wastewater and showed that the efficiency of ammonia conversion to nitrate was maintained at 100% removal up to an inlet total salt concentration of 9 000 mg/l (NaCl concentration was only 4 300 mg/l in this case), after which inhibitory effects were noticed. Adapted biomass was less sensitive to high saline concentrations. The results of Hunik *et al.* (1992, 1993) are comparable, demonstrating that *Nitrosomonas europaea*, and therefore also the nitrification reaction, was severely inhibited by high salt concentrations (above about 200 mM). This was attributed to an osmotic pressure effect. The osmotic effect on *Nitrobacter agilis* was considerably less than that on *N. europaea*. An activated sludge unit subjected to nitrification at 30 000 mg/l NaCl by Dincer and Kargi (2001) also experienced inhibitory effects. In order to achieve complete nitrification at 30 000 mg/l salt, the minimum sludge age needed to be more than double that compared to the salt free wastewater. Research work, carried out by Vredenbregta *et al.* (1997), in fluid-bed reactors gave different results, however. They claim that nitrate and nitrite are removed effectively up to 34 000 and 45 000 Cl^-/l respectively. The work of Panswad and Anan (1999), where it was proved that both nitrifying and denitrifying bacteria were able to adapt well to a high salinity environment (up to 30 000 mg/l), substantiates this argument. They noted that an appropriate recovery period was necessary after a salt loading regime and that acclimation is an important factor in improving the performance of the system.

One of the few reports in the literature on the effect of salt on anaerobic digestion by Liu & Boone (1991) reported that NaCl concentrations up to 4 500 mg/l had little effect on growth rate of propionate, acetate or H_2/CO_2-degrading cultures. However, the growth rate of lignocellulose-degrading populations was inhibited by about 50% at the same concentration. In another system a reactor containing municipal anaerobic sludge with saline industrial waste it was found that gas production was negatively affected when a salt level of 13 000 mg/l was attained.

The rotating biodisc contactor (RBC) is another system where the effect of salt has been relatively well researched (Kinner & Bishop, 1982; Kargi & Dincer, 1998, 1999, 2000; Kargi, 2002). Using RBCs to treat synthetic waste water at an average of 20 000 mg/l Kinner and Bishop (1982) achieved a COD removal rate of between 61% and 64% depending on loading rates and they considered that wastewater, with salinities close to seawater can be successfully treated in these systems. Kargi and Dincer (1999) reached similar conclusions, although above 20 000 mg/l salt content the removal efficiency began to drop until at 10 000 mg/l salt it was only about 45% that of fresh water. In some of their other pilot plants, the inclusion of salt tolerant *Halobacter* species in the cultures, greatly improved the removal efficiency, especially at salinities above 30 000 mg/l (Kargi & Dincer, 1998, 2001). Further investigation into the performance of RBCs showed that in order to attain COD removals greater than 90% in high strength (COD = 5 000 mg/l), high salinity water (>30 000 mg/l), a large area to flow rate ratio (>3 000 $m^2/m^3/hr$) was necessary (Kargi, 2002).

The effect of saline wastewater on trickling filters was evaluated by Lawton and Eggert (1957). They reported that good filter slime was able to develop and reduce input BOD at salinities of up to 30 000 mg/l, but growth was more than three times slower than for weakly saline waste. The filters receiving 40 000 mg/l salt waste were not able to attain the removal efficiency observed in the 2 000 mg/l NaCl wastewater. As with most of the treatment systems mentioned in this review, filter growths suffered a shock effect when subjected to sharp changes in NaCl concentration.

2.1.4 Saline Sewage Treatment Processes – Full-scale Applications

The majority of the research reported in the literature refers to laboratory or pilot scale reactors. However, Tang and Lee (2002) have reported on the effect of mixed fresh and sea wastewaters on Hong Kong’s sewage treatment works. The activated sludge treatment system was reported to have a very high BOD removal efficiency and showed no adverse effect on heterotrophic organisms under saline conditions. In this case the salt concentration of the mixed sewage was only between 5 000 and 6 000 mg/l (about a sixth of sea water). Satisfactory denitrification was found to occur in this system, although nitrification was impaired with an increase in salinity. Tang and Lee (2000) record attempts to overcome these problems by increasing the sludge age and mixed liquor suspended solids. An additional problem encountered with the inclusion of sea water in the treatment works was an increase in the sulphate concentration which led to an increase in H_2S production and, therefore, odour problems. Ferric chloride was added in order to reduce H_2S release in the system. Corrosion problems thus need to be borne in mind.

Another interesting sea water system that has been tested for the full-scale treatment of a sewage discharge is what is known as the Marine Underwater Depuration System or MUDS (Cattaneo-Vietti *et al*., 2003). This is a filtering system that has been placed on the ocean floor, over the sewage discharged from the Mediterranean town of Rapallo in Italy. Different filter surfaces provide for the establishment of an extremely rich variety of organisms, such as bacterial mats, protozoans, flagellates, hydrozoans, foraminifera and ciliates as well as macro benthic predators and filter feeders such as mussels. Fish also aggregate around the device, which basically becomes a type of artificial reef. The density difference between the effluent and the seawater causes the discharge to percolate slowly through the filters. A reduction in total suspended matter, BOD and coliform concentration of about 90% was reported to be achieved with the MUDS installation.

Although the biological treatment of wastewater is generally regarded as a far more sustainable option, it should also be mentioned that physico-chemical treatment is also possible and may be applicable in systems where fresh water works are intermittently loaded with saline wastewater. This type of treatment is not susceptible to shock load and, as it is not necessarily continuous, may be applied only when necessary. Kessick and Manchen (1976) investigated the coagulation, flocculation and sedimentation of solids in saline waste water (20 000 mg/l NaCl) using aluminium sulphate and lime. The aluminium sulphate was equally effective in both fresh and salt water waste whereas the lime was associated with an increase in the non-settleable organic fraction. The increased lysis of cells at a high pH in saline water was thought to be accountable for this effect.

2.1.5 Integrated Algal Ponding Systems (IAPS)

Oswald (1994) has described the development of the Advanced Integrated Wastewater Ponding System (AIWPS) and has noted its many advantages over conventional water treatment systems. The economic advantages are considerable, and Oswald's experience in the USA is that construction costs may be as little as a third and operating expenses about one fifth of comparable, more conventional treatment systems. In tropical or sub-tropical sun-belt areas of the world, where land is generally still relatively inexpensive, he recommends the AIWPS as the preferable water treatment choice. As has been pointed out earlier, many of the coastal, water stressed areas of the world fall in this climatic category. It would be appropriate, therefore, to develop an integrated ponding system that could function satisfactorily, if operated with sea water.

The term AIWPS refers to a specific, trade marked process and relates to a defined process design. However, the concept has acquired wider meaning and Integrated Algal Ponding Systems (IAPS) has been used as a more generic term referring to various combinations of ponding system units and novel applications, involving an algal component in their operation (Rose *et al.*, 2002c).

The IAPS process, from which adaptations have been made for various applications, consists of a number of unit operations (Rose *et al*., 2002c).

Primary Facultative Pond (PFP)

The PFP is the first pond in the series and consists of an anaerobic, fermentation pit, under a layer of aerobic water. Typically a berm or a wall surrounds the pit and this, together with its depth, prevents the intrusion of oxygenated water into the anaerobic zone, which might otherwise occur due to wind mixing. Raw waste is introduced near the bottom of the pit at a velocity slow enough to allow settleable solids to remain in the pit. Helminth ova and most other parasites are also generally heavy enough to settle out in the pit. The algal growth on the surface of the pond contributes photosynthetic oxygen for the aerobic function of this compartment. This upper aerobic layer is also responsible for the oxidation of odour causing compounds. The small quantity of floatables that occur are collected on down wind scum ramps and removed. The outlet pipe's opening is about 1 m below the surface to prevent the transfer of floatables to the secondary pond.

High Rate Algal Pond (HRAP)

This consists of a raceway system which is mixed by paddle-wheels in order to keep the algal floc in suspension, thereby maximising the algae's exposure to sunlight. This gives rise to an extremely high photosynthetic oxygen production and pH increase, both of which result in an effective pathogen kill. The HRAP are operated at a depth of 30cm and a hydraulic retention time (HRT) of 3 days.

Algal Settling Pond (ASP)

The slow movement of water in these ponds and the stable nature of the algal floc cause about 80% of the algae to settle, from where it can be harvested as a potentially useful by-product. Algae should be removed on a regular basis from this pond to prevent decay and the subsequent release of nutrients back into the water.

Maturation Pond

This is used where discharged water may come into contact with humans. A 10 to 20 day storage period in a deep maturation is recommended to provide adequate reduction in the bacterial count. Wells (2005), at the Rhodes University Environmental Biotechnology Research Unit (EBRU) in Grahamstown, reported that a second HRAP run in series provides a far more effective disinfection function with Coliforms reduced to <1 to 10 cfu/100 ml and *E. coli* reduced to <1 cfu/100 ml. In this case a maturation pond is not necessary.

EBRU has experimented with IAPS for the successful treatment of tannery (Rose *et al*., 2002b), abattoir (Rose *et al*., 2002c) and winery wastewaters (Dekker, 2002). Rose *et al*. (2002) implemented a PFP and HRAP treatment stage into the waste stabilisation pond (WSP) cascade, treating tannery effluent at the Mossop-Western Leathers Co. in Wellington. Chloride concentrations for the cascade increase from 4 000 mg/l to about 24 000 mg/l across the WSP, through evaporative concentration. Sulphate and sodium chloride concentrations contribute largely to the total dissolved solids (TDS) of the wastewater and were of more concern in this investigation. Due to the nature of the waste, a *Spirulina* monoculture grows in the WSP. The HRAP, therefore, functions as a Spirulina-HRAP (S-HRAP). At a maximum loading rate of 10% HRAP volume/day, reductions in organic load of 78%, ammonia of 94%, sulphides of 99% and phosphates of 92% was achieved. Dekker (2002) found that IAPS were effective in the removal of nitrogen and phosphorus from wine industry wastewater. Because of the very high COD loads (up to 35 000 mg/l) an anaerobic baffle reactor was needed to attain a COD removal of greater than 95%. Although the TDS of the distillery effluent was up to 18 000 mg/l, very little of this could be attributed to NaCl. A significant removal of heavy metals may also be achieved in the PFP (Wells, 2005).

Another application of the HRAP that has been fairly extensively covered in the literature has been its use for the treatment of effluent from various types of aquaculture. The difference between these systems and those used by the EBG are that macroalgae, instead of unicellular algae, are grown in the ponds. Seaweed (*Ulva sp*.) appears to be very effective in removing nitrogen, phosphorus and ammonia from fishpond wastewater (Cohen & Neori, 1991; Jimenes del Rio *et al*., 1996; Neori *et al*., 1996; Pagand *et al*., 2000; Porella *et al*., 2003).

Neori *et al*. (1998) also found that *Ulva lactuca* successfully removed nitrogen from abalone culture effluent. A major advantage of this form of wastewater treatment is the production of a valuable by-product, i.e. the seaweed, which can be used as feed in a closed aquaculture system (Muller, pers. com. 2003). Although Muller also grows *Gracilaria sp.* and remarked that it is a better protein source than *Ulva sp.*, Neori *et al*. (1998) found that *G. conferta* had highly erratic growth and they deemed it unsuitable for nutrient removal from abalone farm effluent.

2.1.6 Algal Biotechnology

Sustainability, in terms of resource utilisation has been discussed above, but for a process to be fully sustainable it needs to be economically viable. Knox (2003) emphasised this by saying, “in Africa now, a sustainable process is one that pays for itself.” This, however, is often not the case when dealing with waste management. The production of algal biomass from the treatment of wastewater provides a potential avenue where the beneficiation of a waste stream can be realised (Rose, 1992). An efficient mechanism for this production may be the use of algal ponding systems. Converting organic waste into algal biomass, rich in protein, while stripping out nutrients may be accomplished with the only energy input being solar irradiation (Rose *et al*., 2002a).

Rose *et al.* (2002b) have reported the treatment of saline tannery wastewaters using a *Spirulina*-based algal ponding system with the recovery of commercial value in the sale of the harvested biomass into the high-value aquaculture feed industry (Dunn, 1998). Laubscher (1992) had investigated the use of *Dunaliella salina* cultures in the treatment of hypersaline organic wastewaters and evaluated a HRAP for the treatment of tannery effluent in a tannery effluent evaporation cascade. β-carotene was shown to be a potential high-value recovery product from these systems.

The physiological stress response mechanism in *D. salina* relating to the production of β-carotene in saline water systems was investigated by Logie (1995) and Phillips (1995). Phillips (1994) developed a dual-stage system for β-carotene production through process scale-up to the establishment of a commercial-scale production plant in Upington, South Africa. This work has been applied to the treatment of hypersaline wastewaters and Knox (2003) has reported on experimental work undertaken to remove organic contaminants in saline carbonate brines produced at the Botswana Ash Co., Sua Pan, Botswana. In all of the above examples the principle underpinning the research initiative has been that the linkage between wastewater treatment and production of commercially viable products provides the foundation for enduring sustainability of water treatment operations.

2.2 FACT-FINDING VISITS

It was planned that fact-finding visits would be made to the Middle East, Australia and USA during the term of the project to identify progress in the use of saline sewage systems and the management of saline waste waters. Following up of contacts active in saline water research and development in Australia and the USA, indicated that little if any novel developments in the saline sewage field were under development in these countries. It was considered that most current developments were likely to have been already adequately documented in the literature. It was thus decided that given cost considerations, sufficient detail had probably been covered in these areas in order to provide a background against which saline/sewage wastewater co-treatment could be further evaluated.

Contacts were also established with the International Centre for Biosaline Agriculture in Dubai and, given quite close correspondence with work then being undertaken on hypersaline wastewater treatment in WRC Project 1456, it was decided to accept an invitation from the Director-General, Mohammad Al-Attar, to visit the Centre.

The ICBA is a project of the Islamic Development Bank, and focuses on the selection and evaluation of halophilic plant resources suitable for saline agriculture. The Center is located in the desert on the outskirts of Dubai, and an impressive experimental field station and genetic resource base is maintained. Forage and grain crops are grown in water up to 66% salinity of sea water. Medium-saline and low-saline production is also investigated and crops, including African Buffelsgras (*Cenchrus ciliaris)* and also Atriplex (Old Man’s Saltbush), are grown at commercially viable scale.

The removal of sodium and chloride salinity remains a knotty residual problem after biological treatment in some wastewaters, and the downstream utilisation of the water in agricultural production has been considered. The ICBA could provide a useful resource in this regard and they have indicated a willingness to collaborate on such projects. In particular, the work on Atriplex to treat high NaCl salinity mine waters following the BioSURE Process® (WRC Project 1456) could benefit from their experience in the production of Atriplex as an agricultural crop.

It was surprising that no one at the ICBA had any knowledge of the use of sea water for sewage reticulation anywhere in the Middle East. The ICBA is the center of saline water research in the Islamic world, indicating that if the practice is in use anywhere in this area this is not widely known in the saline water research community in the area.

Discussions were held with the following staff at the ICBA:

Dr Mohammad Al-Attar (Director General)
Dr Faisal Taha (Director)
Dr Abdullah Dakheel
Dr John Stenhouse
Dr Sandra Child
Dr Bassam Hasbini
Mr Jugu Abraham

2.3 DISCUSSION AND RECOMMENDATIONS

A review of saline sewage usage has been undertaken. The use of sea water for the reticulation of sewage has been reported from a number of sites including mainly small volcanic islands with limited fresh water resources. Most of this flow returns directly to sea in an untreated form. In Hong Kong, where some sea water is used and treated before discharge, the overall salinity levels are low, thus placing a limited saline load on the treatment works. It is apparent that other sites may well be using and treating sea water/sewage flows but have not shown up in this literature review. On-board small plant sewage treatment on ships provides a good comparative point for the experimental work undertaken here.

An interesting case is the sewerage system draining the marina in Port Alfred, where substantial intrusion of sea water has resulted in a meso-saline treatment works. Oxidation ponds are used here and rich blooms of *Microcystis* sp. have been observed in this system (Rose pers. com.).

Although surprising, it seems that with some noted exceptions such as in Hong Kong, little development has been undertaken on any large scale on saline sewage systems for use in coastal areas. This even in areas such as the Middle East where desalinated water is used for these operations. Nothing was found in the literature on the use of brackish and saline waters in arid inland regions. Again, it seems likely that this is happening but has not appeared in the literature.

Based on these findings, and given the water-scarce conditions in South African coastal Areas which experience repeated water rationing, such as Cape Town, it seems appropriate to commence an investigation of the potential for this form of sewage reticulation and treatment.

3 FEASIBILITY OF THE SALINE SEWAGE OPTION

3.1 APPLICATION

The principal drivers for the use of saline water for the reticulation of water-borne sewage services has been the limitation imposed by access to the available fresh water resource, and the resulting constraints on social and economic development. The environmental impacts of increasing water harvesting and dam building programmes have also been identified more recently, together with impacts on the quality of the receiving water body.

Generally seawater has been the alternative water source most considered in applications of saline sewage discussed in the literature, with very limited reference to sodium chloride brackish waters (1000-10000 mg/l) used in inland regions. No reference was found on the use in sewage reticulation of high sulphate saline waters produced by mining and associated anthropogenic activities, nor on the use of high calcium or magnesium hard waters.

While the potential savings to the fresh water resource of the saline sewage system could be substantial, with 25-35% of total water use budgets in most communities being allocated to black water functions, numerous economic, technical and social factors need to be addressed in considering the possible application of such a system.

3.2 ECONOMIC FACTORS

The cost/benefits of the saline sewage operation are dependent essentially on the costs of dual pipeline reticulation, and separate wastewater treatment infrastructure balanced against the cost savings recovered in the use of the fresh water and the environmental savings accrued in the exploitation of scarce resources.

Any extended use of saline water for the provision of sewage services requires infrastructure for the separate reticulation of fresh and saline water to the user and, where the black and grey waters are to be managed independently, separate sewerage also needs to be provided. Although some applications using sea water combine the saline and fresh wastewater components in the same sewer and discharge back to sea, either with or without final treatment, the separate collection and treatment of grey water, and its recycle and reuse, makes sense in the context of water scarcity where such systems would be considered in the first place.

In its most complete application, the saline sewage operation requires the construction of two parallel water systems including provision, distribution, collection and treatment, and this may effectively double the cost of the water services infrastructure provision. Whether this is installed as a “green fields” operation or as the retrofit of an existing system would also impact substantially on the cost. However, the savings in the costs of fresh water consumption, which is enabled by reduced off-take, and the recovery to recycle of treated grey waters, could make substantial impacts on the total costs of water services provision in large communities. In certain circumstances these savings could also be instrumental in determining the upper constraints limiting social development in certain areas.

Clearly a rigorous treatment of the economics of dual water services provision needs to be undertaken to quantify the cost/benefits associated with the system in various particular applications. This has emerged as a strong recommendation of the study and, given the positive outcomes in other aspects of the investigation, the provision of a detailed techno-economic picture would enable informed decision-making where the option might be considered.

3.3 TECHNICAL FACTORS

In addition to the costs of separate water services provision, a number of issues relating to pipe and sewer corrosion, and the ability to effectively treat the saline wastewaters, have emerged as potential constraints.

Corrosion problems due to sulphide production, as a result of bacterial sulphate reduction activity and sulphuric acid generation in the system, may be resolved by the use of polyethylene or polyvinyl chloride pipes, sewers and toilet components. However, this would be most cost effectively installed in new rather than retrofitted developments.

Although most of the reported applications of sea water use in sewage service provision result in the return and discharge of untreated wastewater back to sea, the impacts of salinity on the operation of a number of different sewage treatment technologies has been reported including activated sludge, trickling filters and rotating disc contactors. Adaptation of these systems to saline conditions appears to be feasible, but fresh water shock loading would be as much a problem to saline treatment systems as saline water has been found to be to fresh water treatment operations.

Reduced oxygen solubility in saline water will raise the costs of oxygen provision in mechanically aerated activated sludge systems and, in addition, sludge production appears to be enhanced in these systems. Where increased retention of mixed liquor suspended solids (MLSS) is required this will raise the capital costs of plant infrastructure. Reports of impaired nutrient removal may be less of a problem where the treated water is discharged back to sea, but may require consideration where phytoplankton blooms are induced in the outfall area.

IAPS applications have been studied in the treatment of saline tannery and distillery wastewaters (Rose *et al.*, 2002a&b; Dekker, 2002), and the improved availability of algal oxygen production in the dissolved form has been noted. Effective nutrient removal and recovery of valuable algal biomass has also been reported. Where the surface area flow ratio increases unfavourably, as has been reported for some saline activated sludge systems, the footprint of the IAPS becomes more favourable in the sewage treatment application.

Based on the above information, it may be provisionally concluded that the saline sewage concept is a feasible proposition in certain applications and under very specific site-related conditions. The economic and technical constraints would also tend to be site-specific but certain generalisations in the overall application of the concept may be possible. More detailed cost/benefit and technical application studies would be needed to determine these points. While the economic evaluation has not been treated here, the technical feasibility of using IAPS technology in managing the treatment of saline sewage wastewaters has been considered further.

4 IAPS IN SALINE SEWAGE WASTEWATER TREATMENT APPLICATION

One of the key elements in the saline sewage proposal is the ability to be able to treat the final wastewater to a standard at least comparable to the quality of the raw water source from which it was drawn. This principle should be the target even in the case of seawater use and return via a marine outfall. In order to evaluate IAPS technology for the treatment of saline sewage it was decided to undertake both laboratory and pilot plant studies, to derive insights into the nature of the system and, if possible, to consider design requirements on which full-scale implementation might be based.

4.1 LABORATORY STUDIES

4.1.1 Materials and Methods

In order to culture a suitably adapted anaerobic inoculum, anaerobic, organic rich, saline sediments were sampled. These samples were obtained from estuaries along the Eastern Cape and Kwazulu/Natal coastlines (Coega Saltworks, Swartkops, Boknes, Bushmans and Kowie River mouths as well as Kosi Bay). The sediments were then added to a 10l flask, together with 1l of primary sewage sludge and filled with sea water. The flask was then sealed and purged with nitrogen to ensure anaerobic conditions.

Once anaerobic digestion was established, and monitored by the stable production of methane, flask studies were initiated. Five flasks were used, consisting of 200 ml of a 0, 10 000, 30 000 and 40 000 mg/l NaCl and sea water blend respectively, inoculated with 10% adapted saline culture. The systems were then batch fed with 10 ml primary sewage sludge and chemical oxygen demand (COD) was monitored over a 22 day period. COD was analysed using a Merck Spectroquant SQ118 and Merck analysis kits. Samples were filtered through Watman GF/C microglass filters. For COD analysis, the samples were diluted 10 times to eliminate chloride ion interference.

4.1.2 Results and Discussion

Figures 1 through 6 below illustrate the results of this study. From the linear regressions drawn through the points on the figures above it is evident that there is a greater COD reduction in the 30 000, 40 000 and sea water flasks (m = 0.01, figures 3-5), than in the 10 000 and 0 mg/l flasks (m = 0.02, figures 1 and 2). The greatest reduction (45%) in COD was obtained in the sea water flask. The lowest percentage removal occurred in the 0 and 10 000 flasks at 33 and 26% respectively.

These results accord well with previous findings that saline adapted microbial cultures do not function well at reduced salinities and *vice versa.*

Because of the small volumes necessary in the flask studies, it was difficult to achieve consistent results and it was, therefore, decided to construct a pilot-scale plant, where more realistic flow regimes could be implemented and studied.

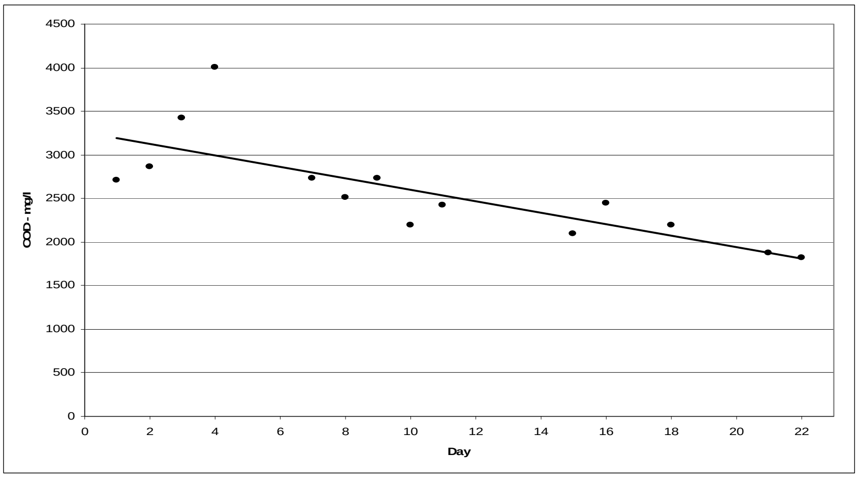


Figure 1: COD removal, using saline adapted culture with 0 mg/l NaCl addition

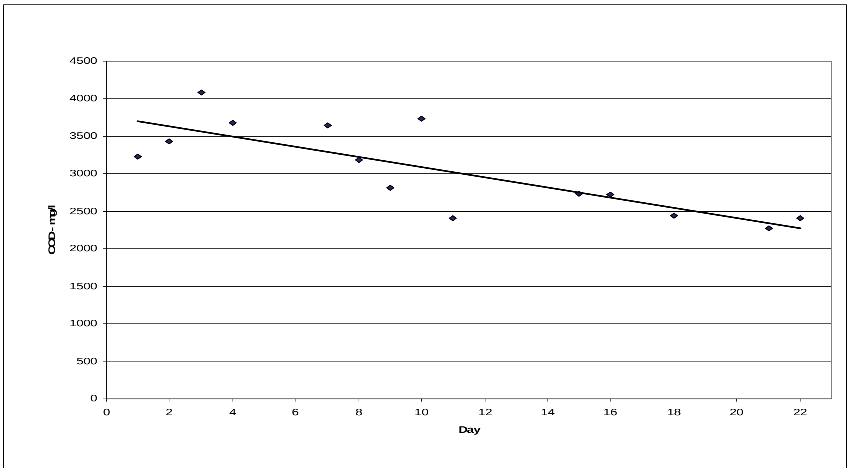


Figure 2: COD removal, using saline adapted culture with 10 000 mg/l NaCl addition

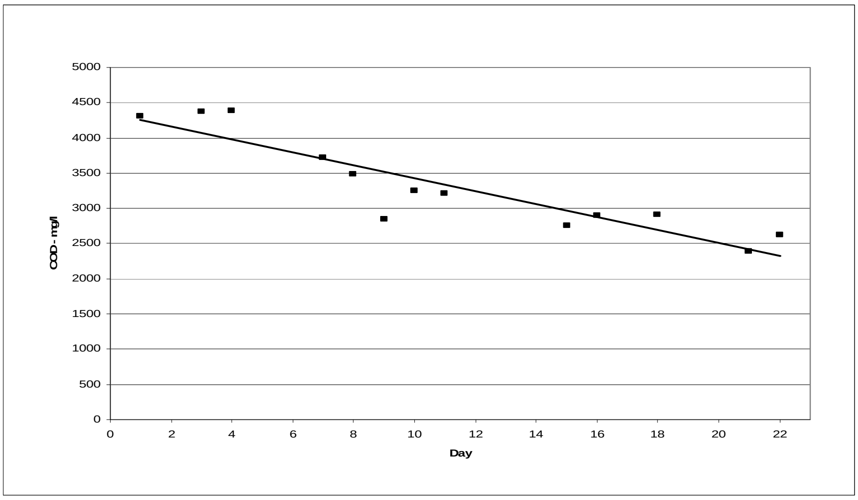


Figure 3: COD removal, using saline adapted culture with 30 000 mg/l NaCl addition

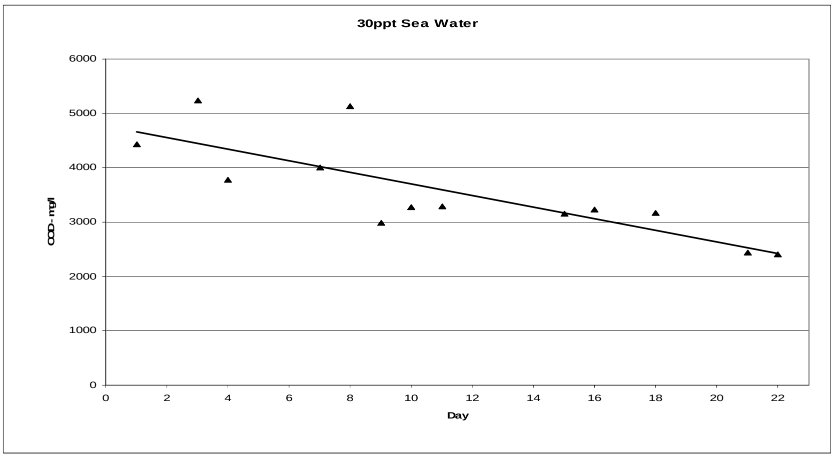


Figure 4: COD removal, using saline adapted culture in sea water

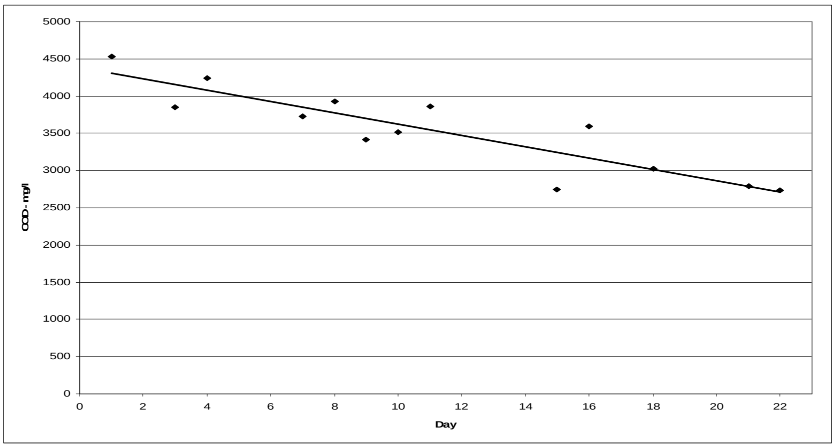


Figure 5: COD removal, using saline adapted culture with 40 000 mg/l NaCl addition

4.2 IAPS PILOT PLANT STUDY

4.2.1 Materials and Methods

The basic IAPS design used in the fresh water sewage treatment studies at EBRU (Rose *et* al., 2002c), was followed in the design of the saline IAPS sewage treatment pilot plant (Figure 6).

The IAPS pilot plant was sized to treat 1 m^3/day of a prepared effluent and to be operated with a 3 day hydraulic retention time (HRT) in the fermentation pit, 20 HRT in the PFP and variable HRT in the high rate algal ponds (HRAP) and algal settling ponds (ASP). In order to achieve a sea water salinity of between 30 and 35 g/l and a COD ~1000 mg/l, raw sewage was blended with a saline concentrate in the ratio of 833:167 l. The blending of the sewage and saline solutions is shown in Figure 6. This was done just prior to dosing into the PFP.

The pilot plant was constructed on site at the EBRU Field Station in Grahamstown and details of the various unit operations are shown in Figures 7-10).

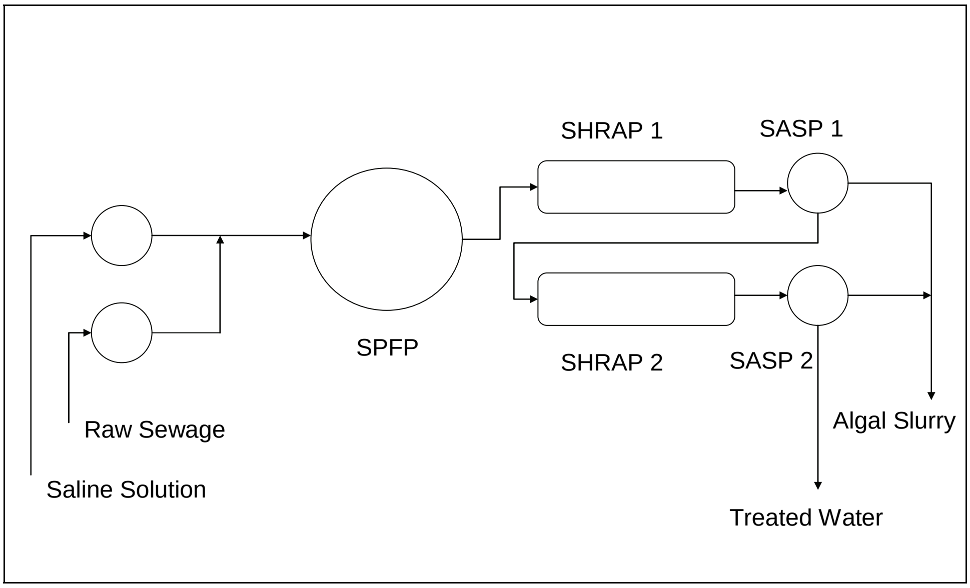


Figure 6: Plan diagram of the Integrated Algal Ponding Systems pilot plant constructed at the EBRU Field Station in Grahamstown. Raw sewage was blended into the saline solution in order to simulate the reticulation of sewage in a saline stream. (SPFP = saline primary facultative pond; SHRAP = saline high rate algal pond; SASP = saline algal settling pond).

Figure 7: The saline IAPS pilot plant installation located at the EBRU campus, Grahamstown

Figure 8: Blending tanks used for the make-up of the saline sewage fed to the saline IAPS system with the anaerobic pit of the Primary Facultative Pond shown in the foreground before its erection

Figure 9: Primary Facultative Pond of the saline IAPS pilot plant

Figure 10: Algal biomass settling tanks and recirculation pump serving the High Rate Algal Ponds of the saline IAPS pilot plant

Figure 7 shows the overall layout of the pilot plant with mixing tanks, PFP and HRAP in the foreground. Figures 8 and 9 show the pre-construction of the PFP pit and then the erection of the pond around that using a portapool structure. Figure 10 shows the algal settling tanks used in this system with return pump to deliver settled HRAP1 effluent back to HRAP2.

A saline-adapted anaerobic methane producing culture was developed from innocula as described above, and salinity was increased incrementally from 10 to 500L. This was then used to inoculate the fermentation pit within the primary facultative pond (PFP) of the pilot plant.

Ammonium as NH_3-N and orthophosphate as PO_4-P were analysed using a Merck Spectroquant SQ118 and Merck analysis kits. Samples were filtered through Watman GF/C microglass filters. The pH was measured with a Cyberscan 2500pH meter, standardised at pH 4.0 and pH 7.0 with SAARCHEM standard buffer solutions. Total Kjeldahl Nitrogen (TKN) was analysed according to Standard Methods (APHA, 1998). Bacteriological analysis was also carried out using the filtration method described in Standard Methods (APHA, 1998). Chromocult agar (Merck) was used as the culture medium for Coliform and *E. coli* counts. Organic removal was measured as total organic carbon (TOC) using a Dohrman TOC analyser.

4.2.2 Results and Discussion

The saline IAPS sewage treatment pilot plant was constructed on-site at EBRU in Grahamstown, and commissioned in May 2004. Following a period of stabilisation it was operated for a period of 9 months from June 2004 to March 2005. Initial results indicated that the saline IAPS has the capacity for effective nutrient removal. Figure 11 shows that the mean phosphate level in the feed water of above 15-20 mg/l is reduced to a mean of less than 5 mg/l in HRAP2. Ammonia generated in the PFP is also effectively removed to ~1 mgl in the two HRAP (Figure 12).

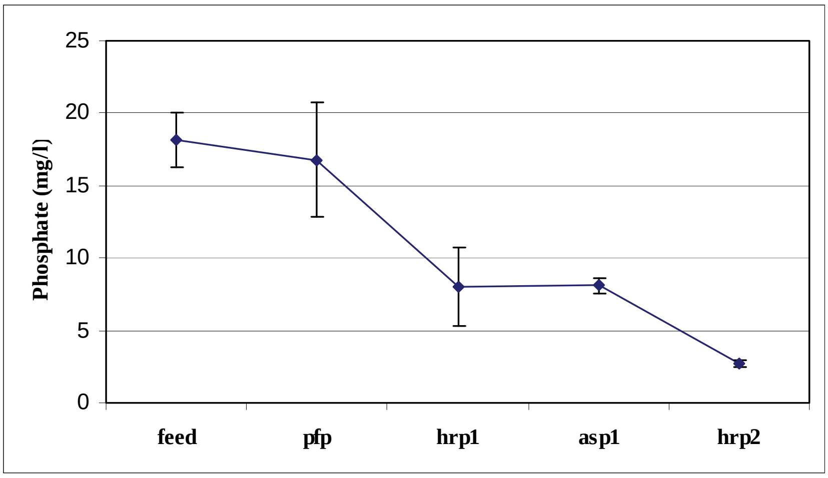


Figure 11: Mean phosphate removal across the saline integrated algal ponding system over the nine month period June 2004-March 2005

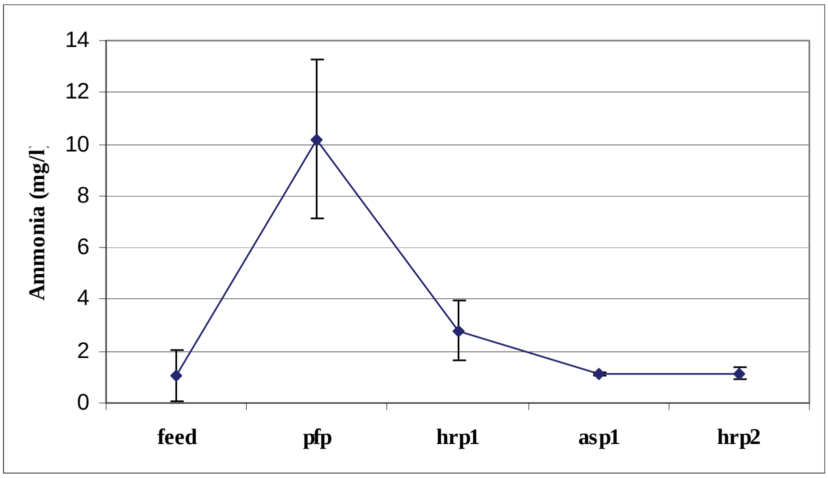
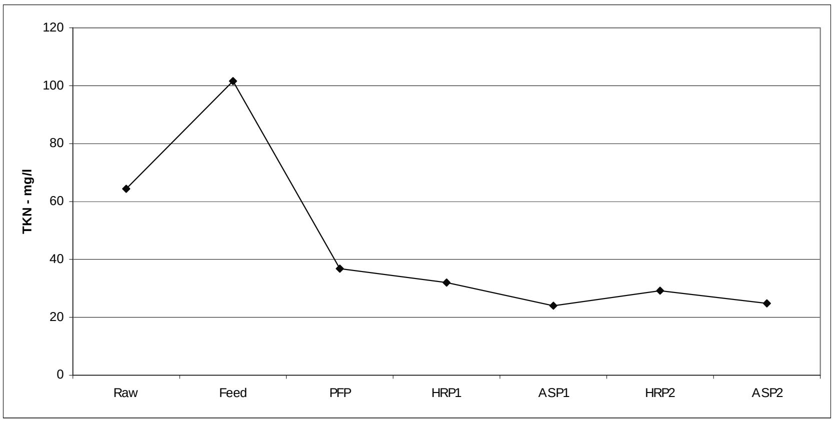


Figure 12: Mean ammonia removal across the saline integrated algal ponding system over the nine month period June 2004 to March 2005

The TKN removal performance results shown in Figure 13, is also substantially reduced in the system with a mean of over 60 mg/l in the feed decreased to about 20 $mg.l^{-1}$ in the final effluent of the saline IAPS system.



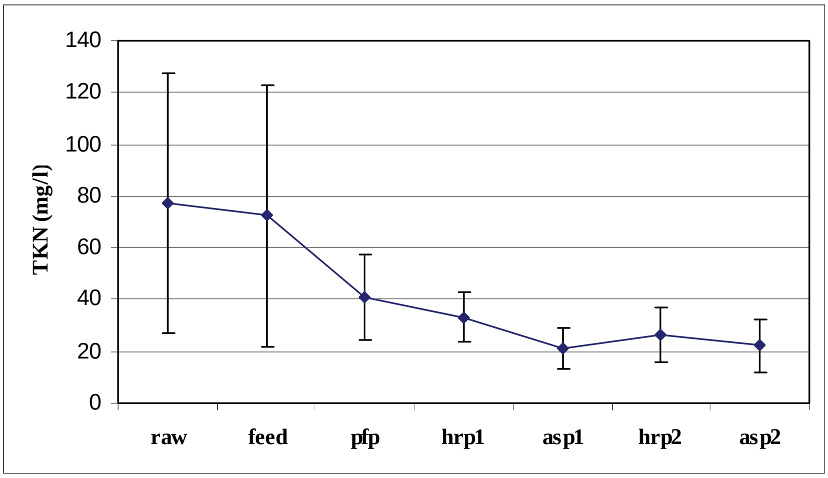


Figure 13: Mean Total Kjeldahl Nitrogen (TKN) removal across the saline integrated algal ponding system over the nine month period January 2004-March 2005

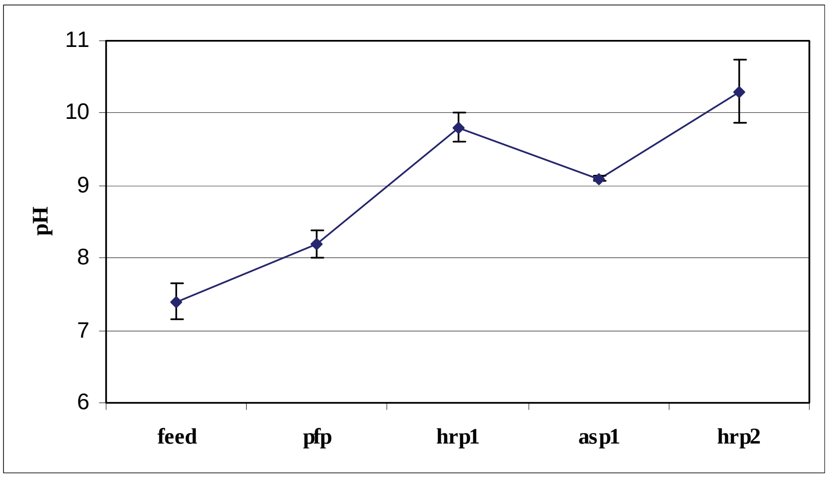


Figure 14: Mean pH across the saline integrated algal ponding system, over the nine month period June 2004-March 2005

The mean pH values in the HRAP, shown in Figure 14, ranged around pH 10 which accords well with observations in the fresh water IAPS. This elevation of pH has been correlated with effective phosphate removal and disinfection in studies on non-saline IAPS (Wells, 2005).

Extensive disinfection studies of the saline IAPS system have not yet been undertaken but preliminary results have indicated that *E. coli* counts in the feed of approximately 9 x 10^7 cfu/100 ml are reduced to <10 cfu/100 ml in HRAP2.

A clear difference noted in the comparison of the freshwater and saline IAPS was the poor settling properties of the algal biomass observed in the ASP. Floc formation was not comparable to the freshwater system that had been operated on the site over a nine year study reported by Wells (2005). It was found that floc formation and algal biomass settling could be improved by increasing retention times in the HRAP. Alternatively, the use of floc builders or of flocculant addition at the end of the process has also been considered. This has been identified as an area requiring further attention.

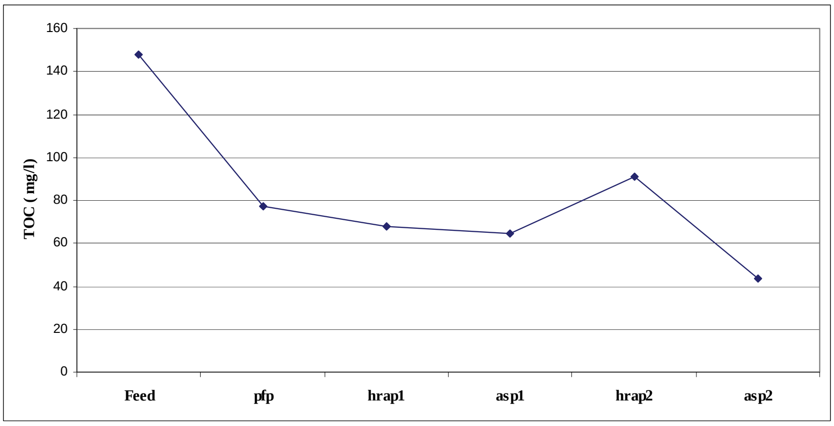


Figure 15: Total Organic Carbon (TOC) removal across the saline integrated algal ponding system

The TOC values for removal of organic components across the system are shown in Figure 15.

4.3 CONCLUSIONS

The flask studies produced useful information in the setting up of the saline sewage system, and confirmed previous findings in the EBRU group that fresh water sewage microbial populations cannot easily be adapted to operate in the 30 000 mg/l NaCl saline environments, and *vice versa*. A range of saline adapted culture innocula were sourced to initiate the study, and those from meso-saline environments (up to 50 000 mg/l) performed best. Since it was not possible to establish stable operating condition in the flask studies, it was decided to proceed directly to the pilot-scale investigation. Also since the system is open, the microbial population established in the system would be mixed. It was thus decided that the microbial population studies would be of reduced importance. However, this could be followed up at a later stage when the full-scale systems were in operation and justifying a comprehensive molecular microbial ecology investigation on a fully representative system.

As with other small-scale systems handling raw sewage problems were experienced in regulating the continuous flow of sewage at low flow volumes used in the pilot plant. Blockages within the raw sewage feed lines being one of the main issues. This resulted in reduced data sets available for periods of stable operation. A number of design modifications to the plant were implemented and these complications were largely eliminated. However, as a result it was considered that detailed design criteria for the establishment of full-scale applications would need to be established at larger scale. This problem had been noted by Prof. William Oswald during the design of the IAPS demonstration plant at EBRU in Grahamstown. At the time he considered an 80 m^3/day feed system to be about as small as could be built and still derive accurate engineering design criteria (Rose *et al*. 2002c). Nevertheless, the results of the current study provide an important indication of what might be expected in the IAPS used in the saline sewage application.

Results of the study obtained thus far suggest that the saline IAPS has the capacity to effectively treat domestic wastewater reticulated in either sea water or possibly other brackish water sources of similar salinity, and to be able to meet discharge standards which are currently required for receiving fresh waters. Numerous teething problems were experienced in the commissioning and operation of the pilot plant and the accurate blending of the raw sewage and saline concentrates to simulate saline sewage flow proved difficult in the low volumes used in this study. Floc formation and algal biomass settling also needs to be addressed to establish appropriate operating conditions. From the studies completed to date it seems that the plant design criteria currently established for fresh water IAPS sewage treatment plants (Rose *et al.,* 2005) may apply, more or less, when operated as a saline system under comparable loadings. Confirmation of this, and the derivation of final detailed design criteria for full-scale applications, will require larger scale studies to be undertaken.

5 RECOMMENDATIONS

The study on saline sewage treatment has indicated that while some experience in the use of sea water for the reticulation of sewage has been reported in the literature, few large-scale applications of such systems have been undertaken. Both economic and technical constraints relate to such systems but advantages in certain site-specific situations would make their implementation favourable. Constraints in cost-effective treatment technology may limit the application. Bench-work and pilot plant studies confirmed indications that the IAPS technology could provide a useful process environment for the treatment of saline sewage wastewaters.

Based on these findings the following recommendations were made:

- While the literature survey produced a certain amount of information on the saline sewage concept, it was evident that more detailed insights would depend on contacts with saline sewage operations. These should be expanded and more detailed information acquired on the status of such systems than is currently reported in the literature.

- With the demonstration of preliminary feasibility of the IAPS saline sewage application, a detailed study of the economics of the saline sewage system should be undertaken to provide inputs necessary for policy decision making;

- The results of the study indicate the viability of the IAPS saline sewage system and it is recommended that the application now be considered for evaluation at larger scale. This would be required for deriving detailed design criteria in order to progress to full-scale application.

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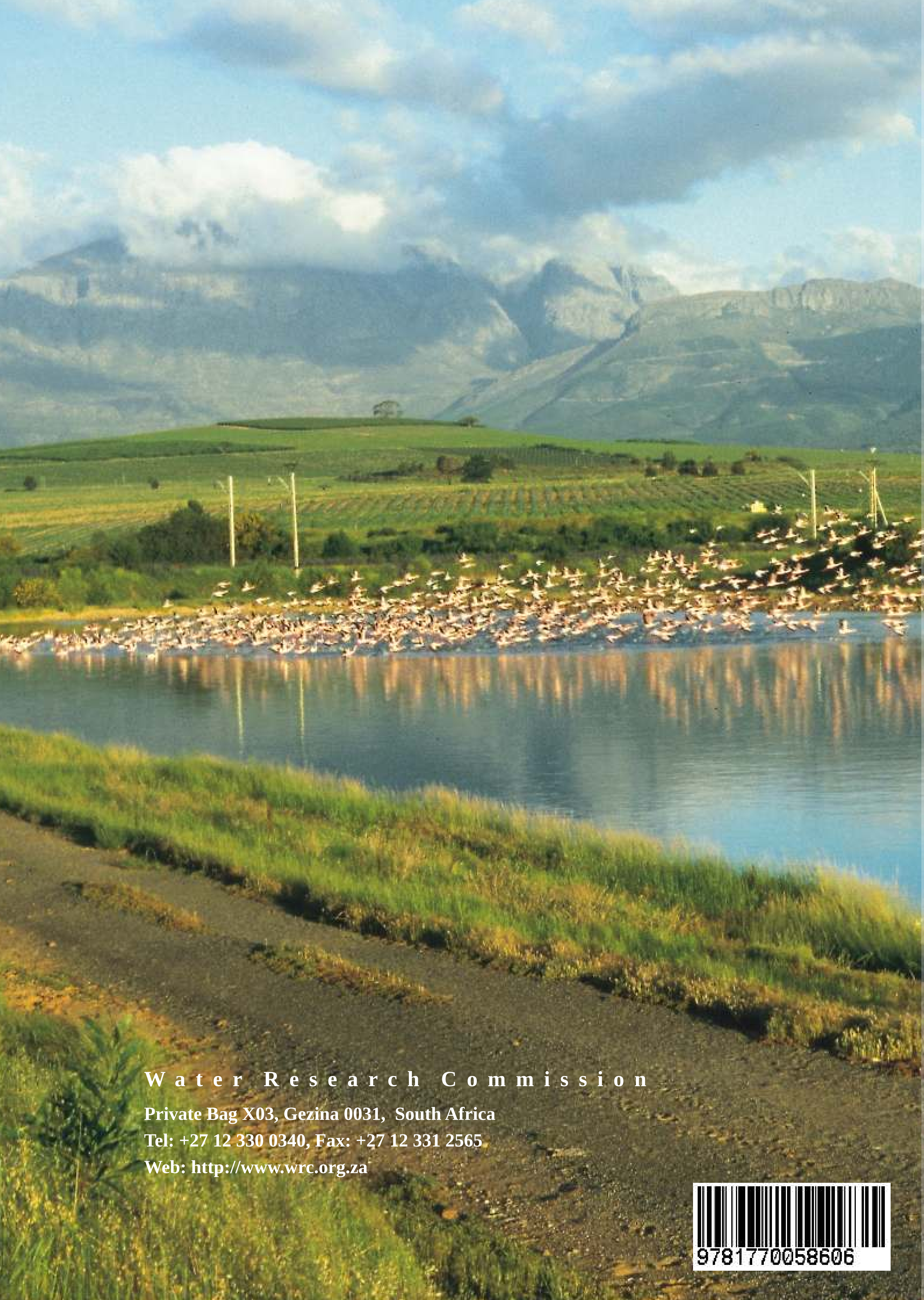

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Private Bag X03, Gezina 0031, South Africa
Tel: +27 12 330 0340, Fax: +27 12 331 2565
Web: http://www.wrc.org.za

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