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 1: The AIWPS Model

Report to the Water Research Commission
By

P D Rose, O O Hart, O Shipin and P J Ellis*
Environmental Biotechnology Group
Rhodes University, Grahamstown
*MBB Consulting Engineers Inc.
Grahamstown

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Project Leader: Prof P.D. Rose

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FOREWORD

The work presented in this series covers a decade of concerted research into critical sustainability issues in the water-scarce Southern African situation. The provision of safe and adequate drinking water and sanitation services to all our people remains a challenge. Pervasive salination from a range of mining, industrial and agricultural activities threatens the quality of our water resources. Simultaneously, the complex ecological needs of the aquatic environment are being understood with ever-increasing clarity.

Significant progress has been made in meeting some of these challenges. In the years since the democratic elections of 1994, millions of previously unserviced South Africans have been supplied with safe drinking water and sanitation services. The problem of increasing salinity of our water resources, with its direct economic impacts and future threat to sustainability, is being addressed at policy and implementation levels, for example by reduction-at-source measures. The ecological needs of the aquatic environment have been recognised by the provision in our water law of a prioritised ecological reserve, to be managed by the catchment management agencies being formed.

Such promising developments notwithstanding, ultimately sustainable resolution of these issues depends crucially also on acquiring appropriate and affordable technologies that provide physical solutions to our water-related challenges. It is in this context that the research described in this series deserves special commendation for the highly innovative biotechnological linkage developed between the treatment of saline wastewaters on one hand and domestic sewage and sludges on the other.

In the novel approach followed, salinity and sanitation issues are each viewed essentially as a resource base (rather than simply as "waste problems") in a suite of integrated process schemes which can be variously manipulated to deliver products of treated water, recovered nutrients and metals, and algal biomass. The paradigm is consequently changed from one of "managing problems" to one of "engineering opportunities", with the potential of offering a major contribution towards the management of water and sanitation in the RSA - some applications have already been taken to full scale implementation, for example in the accelerated digestion of sewage sludge. Significantly, the achievements of this research add weight to biotechnology as "the" technology of the 21st century.

So, as we approach the World Summit on Sustainable Development, we can reflect on the provisions of Agenda 21 adopted after the Earth Summit some 10 years ago, and note that in this time we have ourselves in various ways "done something" about our own situation. And we can therefore point with a justifiable sense of pride and achievement to the body of work presented here as being "Made in South Africa", at a time when social, environmental, political and economic calls are being made to all of Africa to stand up in the continental and global communities of nations.

My deep thanks and appreciation go to the Water Research Commission for the foresight in funding this work, and, in particular, to Prof Peter Rose and his research team at Rhodes University, for the vision, purposefulness, innovation and application with which this work has been conceived and executed.

Ronnie Kasrils

Minister of Water Affairs and Forestry
Pretoria
31 July 2002

PREFACE

This report is one of a series of twelve Water Research Commission studies undertaken by the Environmental Biotechnology Group at Rhodes University, on biotechnology and integration in the management of saline and sanitation wastewater systems. Environmental problems in these areas are reckoned to be responsible for six of the seven priority pollution issues undermining the sustainable development project in Southern Africa. While both salinity and sanitation have separately been the subject of quite extensive investigation, relatively little has been reported on the potential linkage of these systems in meeting sustainable development objectives.

At the time these studies commenced, in 1990, focus on the operationalisation of the sustainability idea had identified 'integrated waste resource management' as a key requirement for progress towards 'closed systems' production. Here human activities, and the associated technological environment, would be detached as far as possible from the bio-physical environment related to natural systems. Waste recovery, recycle and reuse had emerged as major strategies for achieving the radical shift to new technologies which would enable societies to live off nature's income, rather than consuming its capital. Waste beneficiation (a term still more common in the traditional resources sector, and referring to operations that add value by transforming raw material into finished products), was seen as a means of placing treatment operations on an economic footing, with value added in the form of products and services accrued in the waste management operation.

To meet the time-scale of the sustainability agenda, the breakthroughs in technology required would have to be initiated now to guarantee their availability in the next 2 to 4 decades. This led to widespread use of technology-push approaches in sustainable technologies research.

The principal aim of this programme was thus to investigate potential in environmental biotechnology for the development of technological enablement in the linkage of saline and sanitation wastewater management. This involved initial studies in the biology of organic saline wastewater impoundments and an evaluation of the recovery of nutrient values in these wastes in the form of high-value bio-products produced by halophilic micro-organisms. Integrated Algal Ponding Systems were investigated as a 'core technology' in delivering these objectives.

A critical path research methodology was used to identify technological constraints in the organic saline wastewater treatment operation and served to prioritise the research inputs required to underpin bioprocess development. Studies in the microbial ecology and environmental biotechnology of these systems provided the basis for bio-process innovation, and the subsequent development of treatment processes to full-scale engineered applications.

This series includes an introductory volume which provides an overview of the twelve-year programme to date. The reports are listed inside the front cover, and each study in the series is identified by a 'racing flamingo' number, which also appears on the outside cover. This relates to the appearance of a large flock of flamingoes, which took up residence on tannery wastewater ponds following the installation of the *Spirulina*-based Integrated Algal Ponding System developed in the initial studies in this series. The development of the 'Salinity, Sanitation and Sustainability' programme is outlined below in Figure P1, and shows studies in the integrated algal ponding of saline, and domestic and industrial wastewaters, leading to the Rhodes BioSURE Process®, which provides linkage in the treatment of sulphate saline wastewaters and sewage sludge disposal.

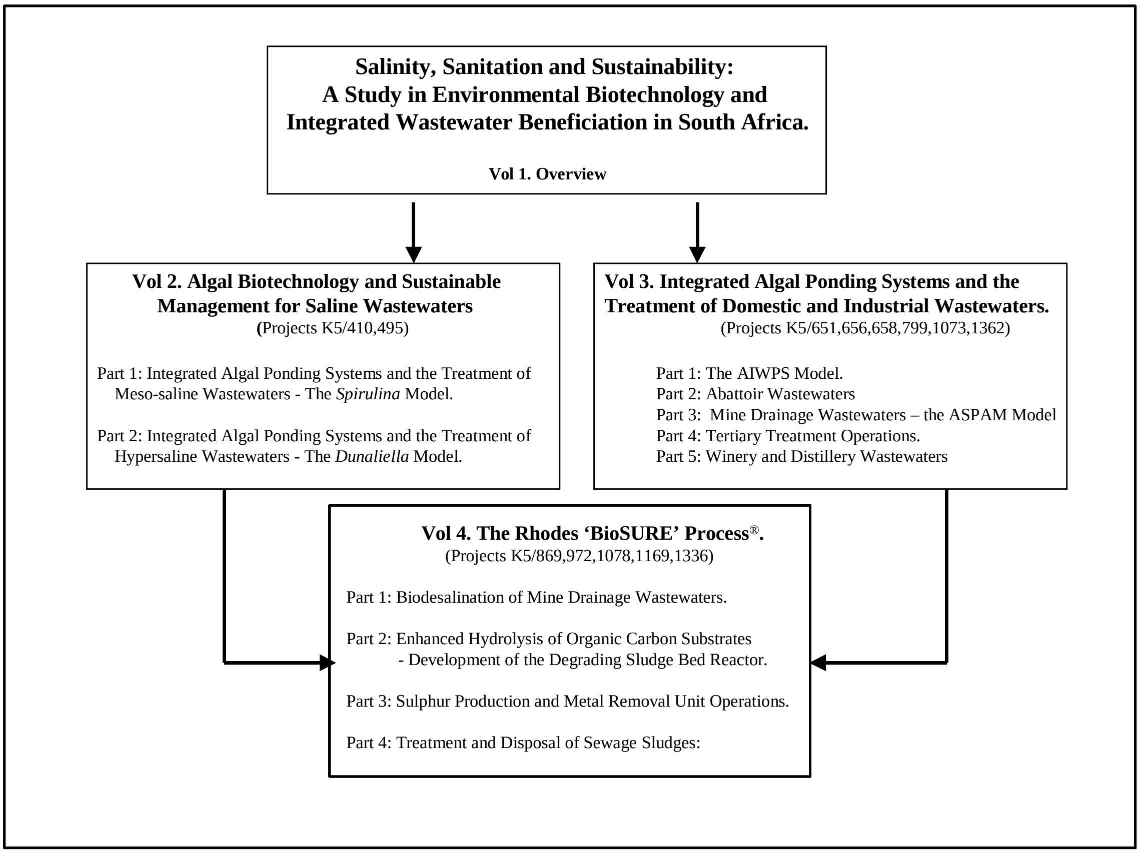

Figure P1. Research projects undertaken as components of the Water Research Commission study 'Salinity, Sanitation and Sustainability'.

A large number of people have assisted generously in many ways in the development of these studies, and are thanked under Acknowledgments. The support of former Water Research Commission Executive Director, Dr Piet Odendaal, is noted in particular. His vision of research needs in water resource sustainability, in the period leading to the Rio Earth Summit in 1992, not only contributed to this study, but also initiated early contributions to sustainable development research in water and sanitation service provision to developing communities. His inputs, together with Research Managers Dr Oliver Hart, Mr Zola Ngcakani, and Mr Greg Steenveld, have made substantial contributions to the development of the ideas investigated in these studies. The contribution and enthusiasm of my post-graduate research students is beyond measure.

Peter Rose
Environmental Biotechnology Group
Rhodes University
Grahamstown

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EXECUTIVE SUMMARY

Integrated Algal Ponding Systems (IAPS) utilise the integration of anaerobic and aerobic biological processes in wastewater ponds to effect the waste water treatment process. Ponds not only provide low-cost reactors, at least an order of magnitude cheaper than concrete structures (Oswald, 1995), but algal photosynthesis yields large quantities of oxygen to support bacterial breakdown of the organic components. Shelef (1987) has noted that these systems epitomise the principles of water and nutrient recycling and close the cycle of waste to primary biomass more rapidly than any other outdoor process; converting organic wastes into an algal biomass rich in protein, while stripping out nutrients. Furthermore all this is accomplished without mechanical aeration but capitalising only on solar energy and, following algal harvesting, producing a high quality effluent not surpassed in quality by other biological or physico-chemical wastewater treatment processes.

This report is part of a 12-year Water Research Commission (WRC) study, undertaken by the Environmental Biotechnology Group (EBG) at Rhodes University, on applications of algal biotechnology and IAPS in an integrated management of the saline and sanitation wastewater problems. These studies have been summarised in the 13-part WRC report series ‘Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa’ (Appendix 7).

Early in the above IAPS application development programme, it was recognised that progress in the development of algal-based wastewater treatment applications in South Africa, would require a matching investment in the development of the engineering skills necessary for their construction and operation under local conditions. In this regard the Advanced Integrated Wastewater Ponding Systems (AIWPS) design, developed by Prof William Oswald over nearly 40 years, at the Sanitary Engineering and Environmental Health Research Laboratory Richmond Field Station, University of California, Berkley, USA, was identified as representing one of the most intensively engineered and developed of IAPS-type applications (Oswald, 1988 a&b; 1995). This process application had been principally focussed on sewage treatment and found to be particularly attractive in low-cost community development projects. Numerous plants operated successfully in both the USA and developing countries. (See Notation for clarification of terminology used.)

1. WRC PROJECT K5/651

Following a visit to California by Professor Rose, and then by WRC Research Manager Dr Hart, to investigate the AIWPS technology in the USA, Professor Oswald was invited to visit South Africa by the WRC in May 1993, to lecture on the principles of the AIWPS concept to scientists and engineers, at various venues. This led to the WRC Project K5/651: ‘Appropriate low-cost sewage treatment using the advanced algal high rate oxidation pond’, which commenced in 1994. This project undertook the technology transfer exercise, in collaboration with Prof Oswald and Dr Bailey Greene, both of University of California, Berkley, California, USA, whereby an AIWPS design was implemented in the construction of an IAPS demonstration and research facility at the Rhodes University Environmental Biotechnology Experimental Field Station in Grahamstown.

This report describes the technology transfer process which resulted in the construction of an AIWPS Plant in Grahamstown. Construction design drawings were prepared by Mr Peter Ellis of MBB Consulting Engineers Inc. in Grahamstown, and construction of the plant was undertaken by Civil and General Construction, Queenstown. The design and construction phase was completed in February 1996 and the first water flowed into the new plant on the 27th of that month. Experiences and problems related to the design, construction and commissioning phases are documented in the report. A schematic diagram of the AIWPS Plant in Grahamstown is shown in Figure 1. Details of the plant are shown in Figures 2 and 3.

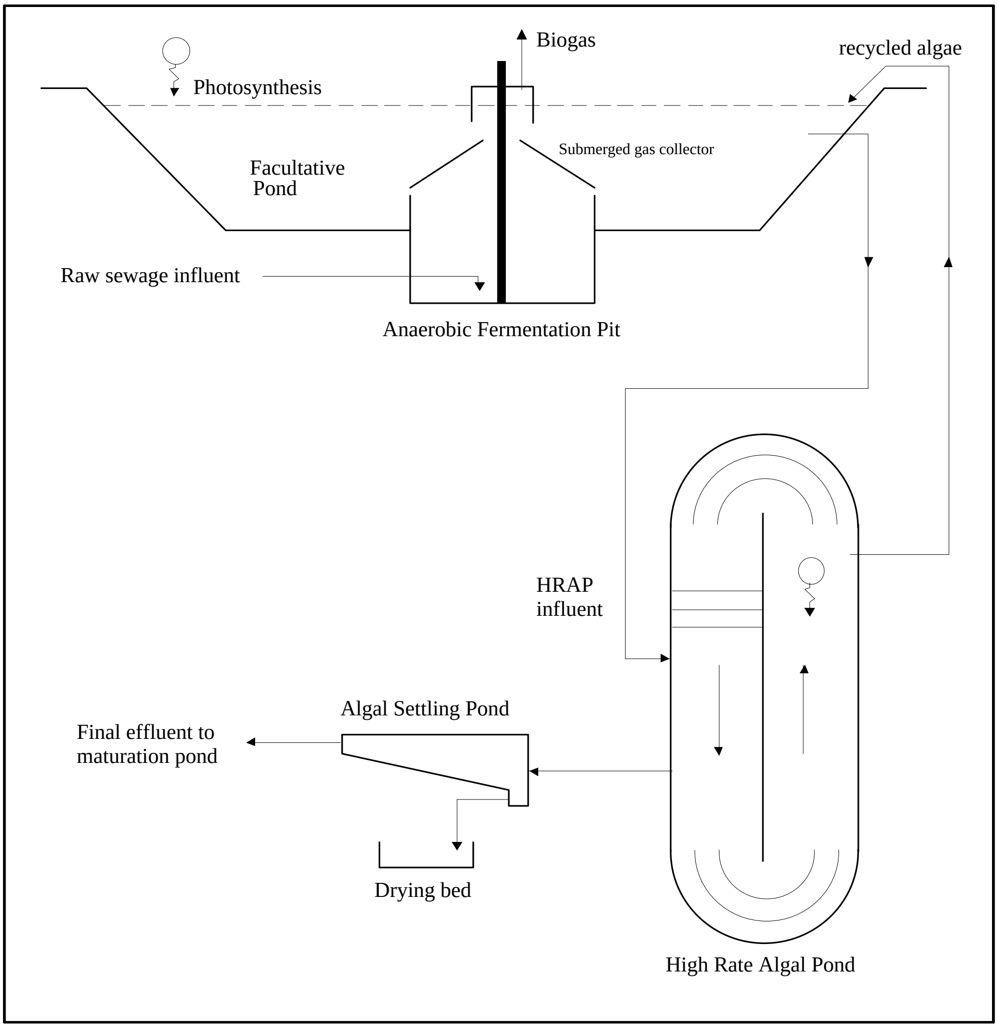

Figure 1 Schematic diagram of the principal unit operations associated with the Advanced Integrated Algal Ponding Systems design constructed at the Rhodes University Environmental Biotechnology Experimental Field Station, Grahamstown Disposal Works.

Figure 2. Primary Facultative Pond of the AIWPS Plant, at the Rhodes University Environmental Biotechnology Experimental Field Station, before and after filling. The access bridge leads to the gas collection unit.

Figure 3. High Rate Algal Pond of the AIWPS Plant, at the Rhodes University Environmental Biotechnology Experimental Field Station, showing paddle wheel and the flow path dividing walls.

Following the establishment of stable operating conditions, the performance of the plant was monitored and the results of these observations are reported. Particularly stable COD removal and buffering of the final treated water quality was observed despite substantial fluctuations encountered in individual unit operations constituting the process. While nitrogen removal was efficient, phosphate and bacterial quality of the treated water required further investigation.

While the principal objectives of the project were achieved, the time allocated to technology transfer, design, construction and commissioning did not allow the accumulation of an adequate data base of operational experience sufficient to make confident predictions relating to the long-term expectations of the system. Problems relating to application in the South African operating condition were identified.

2. CONCLUSIONS

1. The three main aims of the project were realised, including the principal aim, the construction and operation of an AIWPS Plant, completed over the extended three-year period of Project K5/651.

2. The performance of the AIWPS was evaluated only over a relatively short period of time. Nevertheless, excellent COD and nitrogen removal results were observed. While individual units of the process were susceptible to shock loading and climatic effects, particularly the PFP, the system as a whole demonstrated quite remarkable buffering capacity with respect to the quality, and consistency, of the final effluent discharged. However, phosphate levels and total coliform counts were higher than acceptable and it was anticipated improvement in these parameters will require additional attention to fully optimise operation of the system.

3. Quite severe problems were experienced in the operation of the anaerobic pit in the primary facultative pond. Besides its sensitivity to shock load conditions, especially dilutions of COD load, the gas deflector tent design, as installed, has been shown to waste sludge from the pit to the PFP rather than effect its return. As a result a substantial sludge blanket did not form in the pit, which substantially reduced its performance. Further studies on the gas collector are required.

4. A number of technology transfer activities were initiated in the course of the project activities reported here (Appendix 8). These included the opening of both the AIWPS Plant as part of the IAPS demonstration and research facility, and the Rhodes University Environmental Biotechnology Experimental Field Station, by the Minister of Water Affairs and Forestry, Professor Kader Asmal, on 18 April, 1997.

3. RECOMMENDATIONS

A number of aspects may be considered in an extension of the AIWPS technology transfer exercise, together with further development of IAPS technology. The following recommendations have been made:

1. The AIWPS Plant should be operated for an appropriate period as a demonstration plant in order to facilitate the adoption of the technology into routine professional engineering practice in South Africa. It is noted that conservatism in this area requires an appropriate time allocation to the demonstration function. Effective use of resources would be established where the plant simultaneously provides the facility for research development activities;

2. The WRC investment in the AIWPS Plant and the IAPS demonstration and research facility at Rhodes University Environmental Biotechnology Experimental Field Station should be used to pursue the development of algal biotechnology and IAPS applications in appropriate low-cost wastewater treatment in South Africa;

3. The results from Projects K5/651, and follow-up projects K5/799 and K5/1073 should be reported together in a manual format.This would provide construction and

operating design details, an appropriate period of operational experience, an accurate analysis of anticipated costs of construction and operation for appropriate low-cost applications of the system. Research development results relating to the improvements effected to the technology, and a detailed literature review would be reported. This manual should also focus attention on the other applications of WRC technology developments flowing from this initiative and applied to the AIWPS and IAPS treatment of industrial effluents.

4. FOLLOW-UP ACTIONS

The technology transfer initiative, and the construction of the AIWPS Plant in Grahamstown, were undertaken to demonstrate the technology under South African operating conditions, and to provide an engineering support base in the development of IAPS process applications in the treatment of saline and domestic and industrial wastewaters. A number of such application studies took place, both concurrently, and over the 5-year period following the completion of Project K5/651. These developments are noted below and in Appendix 9. Detailed results are reported in the relevant WRC reports (Appendix 7):

1. Development of IAPS in tannery wastewater treatment. A full-scale system was constructed at the Mossop-Western Leathers Co. tannery in Wellington, South Africa;

2. Development of the Independent High Rate Algal Pond (I-HRAP) as a free-standing unit operation in wastewater treatment. A number of applications of the I-HRAP were developed where the recovery of high-value algal bio-products was demonstrated, as waste beneficiation functions of saline organic wastewater treatment operations. These include:

The *Spirulina*-High Rate Algal Pond (S-HRAP) treating meso-saline wastewaters (< 40 $g.L^{-1}$ TDIS). A 2 500 m^2 industrial-scale HRAP was constructed at Mossop-Western Leathers Co. tannery in Wellington and;

The *Dunaliella*-High Rate Algal Pond (D-HRAP) treating hyper-saline wastewaters (> 40 $g.L^{-1}$ TDIS). A pilot plant was constructed at Bostswana Ash Co., Sua Pan, Botswana;

3. Development of IAPS for nutrient removal and tertiary treatment operations in domestic wastewater treatment using the I-HRAP. A pilot plant has been constructed at the Environmental Biotechnology Experimental Field Station in Grahamstown;

4. Development of IAPS for the treatment of abattoir wastewaters. A pilot-scale plant was constructed at the Cato Ridge Abattoir, South Africa;

5. Development of an IAPS hybrid system in the treatment of saline winery and distillery wastewaters. This process development was studied in a pilot plant constructed and operated at the Brennokem Pty Ltd. wine lees plant in Worcester, South Africa;

6. The Algal Sulphate Reducing Ponding Process for Acid Metal Wastewater Treatment (ASPAM), was developed for treatment of acid mine drainage wastewaters. This process involves both the I-HRAP and the IAPS applications in sulphate and heavy metal removal, and in mine wastewater neutralisation operations;

7. The development of the Rhodes Biosure Process® for the treatment of AMD wastewaters was based on studies on complex carbon hydrolysis in the sulphate reducing compartments of IAPS treating sulphate saline wastewaters. The use of these hydrolysates as electron donor sources for sulphate reduction in mine water treatment was undertaken in this process development, and the I-HRAP was used for the final treatment and polishing of the process waters.

ACKNOWLEDGMENTS

The authors wish to express their thanks and appreciation to a number of people and organisations who have assisted generously with the implementation of this project.

- Professor William Oswald of the Environmental Engineering and Health Sciences Laboratory, University of California, Berkeley, California, USA, whose pioneering work over many years has not only inspired much in Algal Biotechnology but has led directly to the AIWPS process. To Prof Oswald and Dr Bailey Green (Oswald Green) for the process design of the Grahamstown AIWPS Plant and their guidance and advice throughout the design and construction stage of the project.

- The Water Research Commission for finance and support throughout the project.

- Grahamstown Municipality for the Demonstration Plant site at the Grahamstown Disposal Works and for providing sewage, water, electricity and maintenance inputs.

- Rhodes University for academic and administrative support.

- Mr Peter Ellis, consulting engineer, MBB Consulting Engineers Inc., for the preparation of the civil engineering drawings in consultation with Professor Oswald and Dr Green, supervision of the project, and enthusiastic support throughout.

- LIRI and Mr Roger Rowswell for inputs and support.

- City of Grahamstown and Mr Trevor Durant, City Engineer.

- Civil and General CC contractors, Queenstown, for the construction of the AIWPS Plant.

- Mrs V Shipin for monitoring and sample analysis.

- All those who served or were observers on the Steering Committee, as detailed below, for their able guidance, support and encouragement throughout the research period:

Dr O O Hart	Water Research Commission (Chairman 1994)
Mr Z Ngcakani	Water Research Commission (Chairman 1995-1996)
Mr G Steenveld	Water Research Commission (Chairman 1997)
Mr P Smit	Water Research Commission
Mr A C Fritz	Water Research Commission
Prof J R Duncan	Rhodes University
Prof P D Rose	Rhodes University
Mr T du Randt	Grahamstown Municipality
Mr T O Horner	Grahamstown Municipality
Mr P J Ellis	Murray, Biesenbach & Badenhorst,Consulting Engineers
Mr P G J Meiring	Meiring Turner & Hoffman Consulting Engineer
Mr R Rowswell	LIRI Technologies, Rhodes University

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ABBREVIATIONS

ADB	Algal Drying Beds
AIWPS	Advanced Integrated Wastewater Ponding Systems
ASP	Algal Settling Pond
BOD	Biological oxygen demand
cal	Calorie
Chl a	Chlorophyll a
COD	Chemical oxygen demand
cm	centimetres
DEAT	Department of Environment Affairs and Tourism
D-HRAP	*Dunaliella*-High Rate Algal Pond
DO	Dissolved oxygen
DWA	Department of Water Affairs (up to 1989)
DWAF	Department of Water Affairs and Forestry (after 1989)
EBG	Environmental Biotechnology Group
GDW	Grahamstown Disposal Works
g	gram
ha	hectare
HRAP	High Rate Algal Ponds
HROP	High Rate Oxidation Pond
HRT	Hydraulic retention time
hp	horsepower
IAPS	Integrated Algal Ponding Systems
I-HRAP	Independent-High Rate Algal Pond
IPWM	Integrated Pollution and Waste Management
L	litre
LIRI	Leather Industries Research Institute (LIRI Technologies)
m	Metres
MPN	Mean probable number
NEMA	National Environmental Management Act
PFP	Primary Facultative Pond
RDP	Reconstruction and Development Programme
R&D	Research and Development
SADC	Southern African Development Community
S-HRAP	*Spirulina*-High Rate Algal Pond
SRB	Sulphate reducing bacteria
SS	Suspended solids
TDS	Total dissolved solids
TDIS	Total dissolved inorganic solids
TKN	Total Kjeldahl nitrogen
t	Time
UN	United Nations
VFA	Volatile fatty acid
WISA	Water Institute of South Africa
WRC	Water Research Commission
WSP	Waste Stabilisation Pond

Design Parameter Abbreviations

A	Surface area
A_{FP}	Area of FP
A_{HRAP}	Area HRAP
$A_{PFP\ mid}$	Mid-depth area PFP
$A_{PFP\ ws}$	Area PFP at water surface
A_{SU}	Area settling unit.
BOD_{ult}	Ultimate BOD
C_c	Concentration algal cells
C_L	Channel length
DA_{ADB}	Daily area requirement of ADB
d_{FP}	Depth fermentation pit
d_{HRAP}	Depth HRAP
d_L	Depth light penetration
d_{max}	Maximum depth
F	Photosynthetic efficiency
h	Heat of combustion of algae
I_{HRAP}	Influent BOD_{ult} to HRAP
I_{SU}	Length settling unit
L_{HRAP}	Loading rate to HRAP
L_o	Organic loading rate
L_{PFP}	Organic load to PFP
PE	Person equivalent
Q	Design flow
Q_{ctr}	Control flow
Q_{HRAP}	Flow to HRAP
Q_{max}	Maximum flow
Q_{Twc}	Worst case total flow
r_{FP}	Radius of fermentation pit
r_{mid}	Mid-depth radius
S	Solar energy flux
TA_{ASB}	Total area ASB
V_{as}	Volume algal slurry
V_{FP}	Volume FP
$V_{overflow}$	Overflow velocity
V_{PFP}	Volume PFP
V_{SU}	Volume settling unit
V_{upflow}	Upflow velocity
W_{SU}	Width settling unit
π	3.1416
θ	Optimal HRT
θ_{FP}	HRT in FP
θ_{min}	Minimum HRT
θ_{PFP}	HRT in PFP

NOTATION

A wide range of terms has been used over the years by different authors to describe various configurations of ponding systems used in wastewater treatment and in algal biotechnology applications. This has created a certain confusion in the literature, and to avoid possible further confusion the following usage has been followed in this study:

- ❑ The term Advanced Integrated Wastewater Ponding System (AIWPS) refers to a specific trade-marked process application design. This ownership of name has been respected and care has been taken throughout not to use the term in a generic sense to cover the many forms of integrated ponding systems involving the use of algal photosynthesis. The term Algal Integrated Ponding Systems (AIPS), and Integrated Algal High Rate Oxidation Ponding Process (IAHROP) which were used in this sense in the earlier part of this study to describe the hybrid algal ponding systems, the development of which was under consideration in this programme, has been changed to Integrated Algal Ponding Systems (IAPS) to avoid confusion;

- ❑ The IAPS is used here to refer generically to combinations of ponding system unit operations involving an algal component in their operation;

- ❑ The term High Rate Algal Pond (HRAP) has been used here and replaces High Rate Oxidation Pond (HROP) used in some literature references, as it is not necessarily inclusive of the algal component;

- ❑ The terms algae or micro-algae are used for convenience in the more traditional sense, broadly covering both the eucaryotic algae as well as the cyanobacteria.

1 INTRODUCTION

1.1 SALINITY AND SANITATION

The continued availability of water, the most fundamental of natural resources, to both environmental and human requirements, presents one of the most serious challenges to the sustainable development project in Southern Africa (DEAT, 1999). The predicament of a rapidly accelerating demand, against the background of increasing pollution and degradation of the finite resource, has been the subject of growing concern over many years (Commission of Enquiry into Water Matters, 1970; Stander, 1987; DWAF, 1989; DEAT, 1999,2000). The National State of the Environment Report (DEAT, 1999), has highlighted the ongoing degradation of the National water resource, and notes that water will increasingly become the limiting resource in South Africa, with supply becoming a major restriction on the future socio-economic development of the country. The recent White Paper on Integrated Pollution and Waste Management has identified salinity and sanitation issues as six of the seven priority sources of pollution, and that the development of locally appropriate treatment technologies to deal with these problems requires urgent attention (DEAT, 2000).

This report is part of a 12-year Water Research Commission (WRC) study, undertaken by the Environmental Biotechnology Group (EBG) at Rhodes University, Grahamstown, on applications of biotechnology in an integrated management of the saline and sanitation wastewater problems. These studies have been summarised in the 13-part WRC report series ‘Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa’ (Appendix 7).

These studies commenced in 1990 with the project ‘A biotechnological approach to the removal of organics from saline effluents’and was based on studies of saline algal biotechnology undertaken by the EBG from the mid-1980s. Evaluation of aquatic photosynthetic production in the micro-algae had developed rapidly since the 1970s and, given photosynthesis as the most abundant energy storing process on earth, the use of algal systems in industrial production of speciality biomass and high-value fine chemical products, was identified as offering opportunities to develop long-term waste beneficiation and sustainability targets.

The objectives of the WRC study had been informed and shaped within the climate of the sustainability idea, emerging around the time of the 1987 World Commission on Environment and Development (WCED, 1987), and in the period leading up to the United Nations Conference on Environment and Development in Rio de Janeiro (UN, 1992). Focus on operationalising sustainability had targeted issues of non-renewable resource depletion, and suggested that new technology would be required to enable societies to live off nature’s income rather than consuming its capital (Speth, 1990). Issues in waste minimisation, waste recovery, recycling and reuse were increasingly investigated, and waste beneficiation, as operations that add value by transforming materials from a raw-material status into finished products, had been identified as an important incentive in shifting the delivery of sustainability targets, from regulatory and coercive approaches, to market-driven implementation (Rose, 1991). However, few studies in algal biotechnology had examined technological constraints in saline wastewater treatment, and little work had been reported on the potential linkage of the saline and sanitation wastewater systems.

1.2. WRC STUDY IN INTEGRATED ALGAL PONDING SYSTEMS

The initial WRC feasibility study K5/410 led to a 5-year follow-up project with the same title (K5/495 ‘A biotechnological approach to the removal of organics from saline effluents’) in which the development of Integrated Algal Ponding Systems (IAPS) technology was applied to the treatment of saline organic wastewaters (Appendix 7). This study had focussed initially on the micro-algal ecology in tannery Waste Stabilisation Ponds (WSP), as a model system for investigating algal-based treatment of both saline and organic wastewater loads. Tannery wastewaters represent a possible worst-case scenario of what might be anticipated in saline wastewater impoundments and, in addition to high concentrations of organic matter and salts including sulphates, a range of heavy metals, nitrogenous and contaminating organic compounds occur.

This project resulted in the development of a novel algal-based technology for treating tannery wastewaters (Rose and Cowan, 1992 a,b,c), and in addition to the production of an animal feed-grade *Spirulina* biomass product, linkages in the treatment of saline and sanitation wastewaters was also demonstrated. This included the use of sulphate saline wastewaters for the disposal of sewage sludges, and the development of the Rhodes BioSURE Process® using waste organic matter as the electron donor source in the biological treatment of acid mine drainage wastewaters (Appendix 7).

In the course of the development of IAPS technology in the treatment of saline and sanitation wastewaters the following was also shown:

❏ Saline and sulphate-saline wastewaters may be feasiblely treated in algal ponding systems and, with the removal of organic and metal pollutants, may be rendered safe for segregation from the public water system in saline wastewater impoundments. This will provide increased safety in saline wildlife refuge areas and recreational wetlands, aspects of which inevitably develop around these sites;

❏ The IAPS concept provides a useful base as a ‘core technology’ for bioprocess innovation in both saline and sanitation wastewater treatment applications. These include small community sanitation, where technological sustainability may be achieved in terms of low-cost construction and operation, a low operational skills requirement, and ‘upgradeability’ to include the treatment of industrial wastewaters as communities develop economically;

❏ Nutrient values present in both saline and sanitation wastewaters may be recovered in IAPS in the form of value-added algal bio-products, and their return to both the economy, and the biological environment, provides enabling technologies for establishing 'integrated wastewater resource management' beneficiation objectives in the management of these wastes;

- The co-disposal of sulphate-saline and domestic wastewaters as linked utility operations provides not only for novel processing in organic waste disposal but, importantly, also for the long-term treatment of AMD following mine closure, an issue directly affecting the sustainability of the mining environment;
- In addition to a range of other possible by-products, treated water may provide the most durable product of the algal-based beneficiation process. Where a cycle of productive use is allowed following wastewater treatment, this may present the strongest incentive to the private operator to undertake the beneficiation of these wastes.

1.3 THE AIWPS - A MODEL SYSTEM

Early in the above IAPS application development programme, it was recognised that progress in the development of algal-based wastewater treatment applications in South Africa, would require a matching investment in the development of the engineering skills necessary for their construction and operation under local conditions. In this regard the Advanced Integrated Wastewater Ponding Systems (AIWPS) design, developed by Prof William Oswald over nearly 40 years, at the Sanitary Engineering and Environmental Health Research Laboratory, Richmond Field Station, University of California, Berkley, USA, was identified as representing one of the most intensively engineered and developed of IAPS-type applications (Oswald, 1988 a&b; 1995). This process application had been principally focussed on sewage treatment and found to be particularly attractive to low-cost community development projects. Numerous plants operated successfully in both the USA and developing countries (see Notation for clarification of terminology used).

Following a visit to California by Professor Rose, and then by WRC Research Manager Dr Oliver Hart, to investigate the AIWPS technology in the USA, Professor Oswald was invited to visit South Africa by the WRC, in May 1993, to lecture on the principles of the AIWPS concept to scientists and engineers, at various venues. This led to the WRC Project K5/651: 'Appropriate low-cost sewage treatment using the advanced algal high rate oxidation pond', which commenced in 1994. This project undertook the technology transfer exercise, in collaboration with Prof Oswald and Dr Bailey Greene, both of UC Berkley, California, USA, whereby an AIWPS design was implemented in the construction of an IAPS demonstration and research facility at the Rhodes University Environmental Biotechnology Experimental Field Station in Grahamstown.

2 THE ADVANCED INTEGRATED WASTEWATER PONDING SYSTEM

2.1 DEVELOPMENT OF THE AIWPS PROCESS

In the early 1960's, John Stauff, a design engineer with Carl Yoder and Associates, asked his former engineering classmate William J Oswald to suggest an innovative process design for the City of Helena's new wastewater treatment plant. Since their graduation from the Sanitary Engineering program at UC Berkeley in 1950, Oswald had become deeply involved in research on the role of microalgae in the treatment of wastewater. Based on his research conducted at UC Berkeley's Institute of Engineering Research (now the Sanitary Engineering and Environmental Health Research Laboratory of the Richmond Field Station), his consultations with Al Hyatt, the City Engineer for Woodland, where Oswald and his student Joe Bronson conducted some of the first biogas analysis in oxidation ponds, his work with sludge digestion at the Concord treatment plant, and his familiarity with the work of Guy Parker in Australia, Professor Oswald began to formulate a ponding system design that would provide for the removal of suspended solids, the growth of methane bacteria, photosynthetic oxygenation of primary effluent, and disinfection. Oswald recounts his thinking at the time:

“In conventional wastewater treatment, solids from primary and secondary sedimentation are put into a digester for 40 days. They are then removed, dried, and buried. Why not bury them in the first place? The conventional digester 40-day residence time does not permit complete digestion. It only conditions the sludge to drain and dry quickly. Why not build a Parker-type, deep pond with a volume big enough so that all the settled solids can remain and digest for hundreds of days and put that pond inside a bigger pond where algae could grow and produce oxygen to destroy odours? Why not then have a second pond where algae are grown under optimal conditions of light and mixing? When algae are grown under such conditions, they increase the pH and produce dissolved oxygen. So why not recycle this oxygen for disinfection and odour control? Then settle and remove the algae for use as a fertilizer or animal feed. Finally, why not add maturation ponds for further disinfection prior to discharge or reclamation?”(Oswald, 1987).

The above thinking of Professor Oswald resulted, after more than forty years of research and application, in the development of the AIWPS design. Although many variations of the concept have been investigated and used either separately, or in combination with WSP systems (Mara and Marecos do Monte, 1987; Mara *et al*., 1996), the now trade-marked AIWPS provides possibly the most precisely engineered example of the IAPS approaches to wastewaters treatment.

2.2 THE SYSTEM

The AIWPS design, in terms of its unit processes operations, is similar to those of conventional wastewater treatment plants. These involve primary sedimentation, flotation, fermentation, aeration, secondary sedimentation, nutrient removal, storage, and final disposal. The methods by which these unit processes are fostered are, however, unique to AIWPS (Figure 2.1).

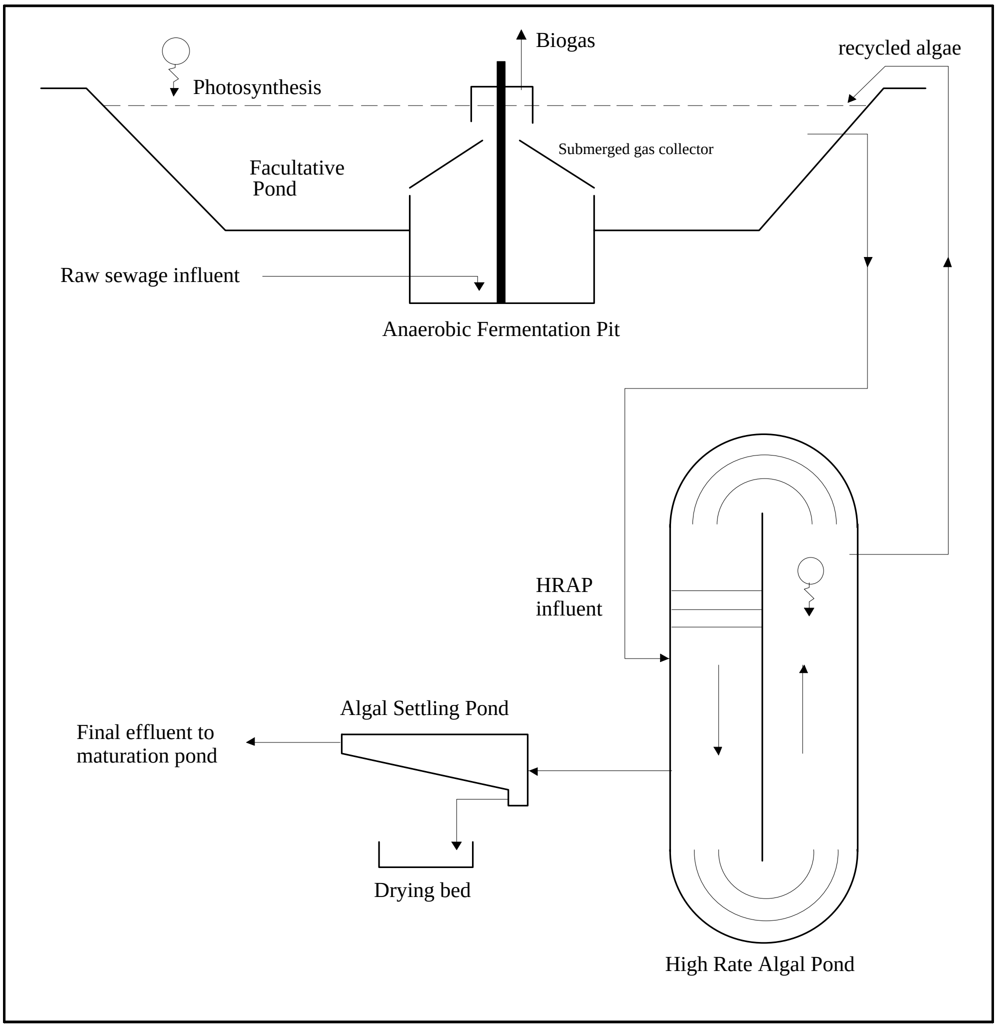

Figure 2.1 Schematic diagram of the principal unit operations associated with the AIWPS Plant design constructed at the Rhodes University Environmental Biotechnology Experimental Field Station, Grahamstown Disposal Works.

The system is composed of a four-pond series and for a full discussion of development, concept and design of the AIWPS, see Oswald (1988 a&b;1995).

2.2.1 Primary Facultative Pond

The first of the four-pond series is the Primary Facultative Pond (PFP), in which the anaerobic bottom zone is overlayed with surface aerobic waters, creating thereby two functionally separate compartments in the pond. A chronic problem with conventional WSP has been that during windy periods inversions and water mixing occurs, which carries oxygenated waters into the anaerobic zone, and inhibits the anaerobic digestion processes. Fermentation pits are constructed in the base of the PFP in which solids sedimentation and anaerobic processes take place, and these are designed with a surrounding berm or wall to prevent the intrusion of oxygenated water.

Raw waste is introduced near the bottom of these pits and, since they are deep, most of the settleable solids remain within the pits. Overflow velocity is designed to be low enough (less than 1.5 m/day) so that most helminth ova and other parasites also remain in the pit. Particulate solids are lifted by bubbles of biogas which form on and in them, but as these rise the bubbles expand and break away leaving the solids to resettle. The result is that solids accumulate within the pits creating an anaerobic sludge blanket through which all of the wastewater must flow.

Carbon dioxide in the biogas becomes available to support algal growth in the upper layers of the PFP, and the generation of photosynthetic oxygen provides, in part, for the aerobic function of this compartment. The upper aerobic layer is also responsible for particularly effective entrapment and oxidation of odour causing compounds. The low-odour characteristics of these systems has enabled their construction in close proximity to urban developments, and has focussed interest in their use in strategies where smaller dispersed wastewater treatment plants replace large centrally located treatment works.

To deal with floatables, PFP are designed with down-wind concrete scum ramps where floatable trash can be cast up by the wind to dry. These substances are largely inert, light in weight and low in odour. They can be collected periodically with a loader for burial or disposal as a solid waste. Since overflowing PFP are constant in depth, bank erosion is best controlled with a paved water line.

Depth is regulated in the PFP by the level of the invert of the outlet pipe. The inlet of this pipe should be located about 1m below the surface to avoid transfer of floatables into the secondary pond.

2.2.2 High Rate Algal Pond

The High Rate Algal Pond (HRAP) provides the most effective design for the second unit operation of the AIWPS. This paddle-mixed raceway requires short retention times of 3-5 days, and produces much more dissolved oxygen than a conventional secondary Facultative Pond. Algae in these systems form stable flocs, which settle readily, and > 80% of the algal cells present in the system may be removed in a short residence time Algal Settling Pond (ASP). This biomass has a low respiration rate and may remain concentrated in bottom of the ASP for a period of weeks or even months without releasing significant amounts of nutrients.

Algal photosynthesis in the HRAP tends to raise the pH of the treated waters, and a pH of 9.2 for 24 hours will provide a 100% kill of *E.coli* and most pathogenic bacteria and viruses. It is not uncommon for the HRAP to reach pH levels of 9.5 to 10 during the day, so a high rate of disinfection is normally achieved.

Because a surplus of dissolved oxygen is produced in the HRAP (usually several times the applied BOD), some of this partly-treated effluent is used to overlay the PFP with warm oxygen-rich water. This absorbs odour-causing compounds generated in the fermentation pits, and assures the presence of oxygen producing algae in the surface waters of the PFP.

2.2.3 Algal Settling Pond

As indicated above, the HRAP should be followed by an algal settling pond ASP or some other method of removing algae. If the water from the HRAP is to be used for irrigation, algae need not be removed, but settling and storage should be sufficient to achieve a bacterial MPN $<10^3$ which is sufficient for irrigation waters.

Harvesting and removal of the algal biomass component of the treated water is required prior to discharge into public water bodies, although the algae may be beneficial to the food chain in the local ecosystem. There is little evidence that this biomass is harmful in moving waters. As uses for waste-grown algae become established, such as its use in animal feeds, fatty acid, plant hormone and pigment extraction, the potential exists for adding value to the treatment process and providing an incentive for integrated resource management in wastewater treatment.

Although natural sedimentation of algae from a paddle-wheel-mixed HRAP is sufficient to remove >80% of the algae, if higher degrees of removal are required mechanical harvesting is indicated. In the Grahamstown AIWPS the settled algae from the ASP is pumped onto underdrained sand beds for drying and harvesting for evaluation purposes.

2.2.4 Maturation Pond

Where AIWPS-treated waters are to be discharged under conditions leading to possible human contact, storage for 10 to 20 days in a deep maturation pond may be used instead of chlorination, and will provide adequate reduction of the bacterial count. The maturation ponds provide valuable wetland environments and are often occupied by wild water fowl, and many other forms of wildlife. These may, however, also impart high but innocuous Mean Probable Number (MPN) loads to maturation pond effluents.

3 IMPLEMENTATION OF THE AIWPS PROCESS IN SOUTH AFRICA

3.1 BACKGROUND

Following the initial visit of Professor Oswald to South Africa in May 1993, the EBG was awarded the WRC Project K5/651 'Appropriate low-cost sewage treatment using the Integrated Algal High Rate Oxidation Ponding Process' as a 2 year project starting in January 1994. The principle objective of this initiative was the construction of an IAPS demonstration and research facility at the Rhodes University Environmental Biotechnology Experimental Field Station in Grahamstown, and involving a technology transfer function with the implementation of the AIWPS process design in South Africa.

3.2 AIMS

The aims of Project K5/651 were identified at the outset as follows:

1. The building and operation of an Integrated Algal High Rate Oxidation Pond (HROP) for the treatment of domestic sewage.

This Demonstration Plant would aim to effect the transfer of currently best available technology world-wide on the design, construction and operation of these systems, with specific application as appropriate technology, low-cost systems for small and developing communities.

2. To evaluate the manipulation and control of algal and bacterial growth and species in the HROP system.

3. The recovery of algal metabolites and other products of value from the microrganisms in the HROP system.

3.3 PLANNING

Prof Oswald visited South Africa a second time in January 1994 to attend an International Anaerobic Digestion conference in Cape Town. During this visit Prof Oswald was joined by his senior research associate, Dr Bailey Green, who was previously involved in the visit of Professor Rose to the University of California, and follow-up discussions during the Seventh International Conference on Applied Algology held in the Czech Republic in October 1993.

On January 22, 1994, a meeting was held at the Grahamstown Municipality offices in Grahamstown to discuss the design and operation of the proposed pilot-scale demonstration AIWPS at the Grahamstown Disposal Works (GDW). Following the discussions, the meeting continued during a site visit to the GDW. Participants in the preliminary design meeting included:

Prof William Oswald, Emeritus Professor of Environmental Engineering and Public Health, Environmental Engineering & Health Sciences Laboratory, University of California, Berkeley, California, USA;
Dr Bailey Green, Assistant Research Engineer, Environmental Engineering & Health Sciences Laboratory, University of California, Berkeley, California, USA;
Mr Trevor Durant, City Engineer, Grahamstown Municipality;
Mr Raymond Theron, Chief Health Inspector, Grahamstown Municipality;
Prof Peter Rose, Professor in Department of Biochemistry & Microbiology and Director of Leather Industries Research Institute, Rhodes University, Grahamstown;
Mr Roger Rowswell, Environmental Manager, Leather Industries Research Institute, Rhodes University, Grahamstown;
Mr Peter Ellis, MBB Consulting Engineers Inc., Grahamstown;
Mr Pieter Meiring, Consulting Engineer, Meiring, Turner & Hoffman C.C Lynwood Ridge, Pretoria;

The primary objectives of the meeting were:

- ❑ to determine the size and location of the demonstration AIWPS;
- ❑ to gather information concerning the characteristics of Grahamstown municipal wastewater;
- ❑ to determine the scope and schedule of services that each member of the project team would provide;
- ❑ to discuss the demonstration, training and technology transfer objectives of the overall project.

It was agreed at the meeting that MBB Inc. would assist in the decision-making process by surveying the identified site and locating the various preliminary design structures forming part of the AIWPS.

A plan entitled “Proposed Five Hundred Persons Pilot-Scale Advanced Integrated Ponding System” was submitted to Professor Rose on 10 March 1994 for comment.

3.4 IMPLEMENTATION

At a meeting on 8 March 1994 attended by the Grahamstown City Engineer Mr T Du Randt, Professor P Rose and Mr P J Ellis of MBB Inc., it was agreed that MBB Inc. in close liaison with Professor Oswald and Dr Green, consulting as Oswald Green, would prepare the detailed drawings of the various components which make up the Pilot AIWPS process, and project manage the construction of plant infrastructure.

MBB Inc. anticipated that the design and construction planning process could be finalised by June 1994, with construction anticipated to take place over a period of 6 to 7 months, and with completion estimated by the end of 1994.

Preliminary drawings for the facultative pond, fermentation pit, high rate ponds, settling ponds and drying beds were presented for discussion and comment on June 9 1994. Following comment, construction plans were faxed to Oswald Green by MBB Inc. on July 6 1994 and correspondence on finalisation of the construction design was completed on October 5, 1994. Communication by letter and fax between Grahamstown and Berkeley, during which the design and construction details were finalised, involved considerably more time than had been anticipated. Interaction with Oswald Green on construction details continued throughout building operations.

At the inaugural meeting of the Project Steering Committee, held on 21 July 1994, it was decided that, given the practical time constraints in effecting the full technology transfer and consultancy process, the project target dates be adjusted as follows:

Design	January - October 1994
Construction	October 1994 - April 1995
Start-up	April - August 1995
Monitoring	August - December 1995

It was also evident that the process monitoring and algal biomass evaluation components of the project would have to assume a lower priority.

Construction commenced on October 25 1994, and was undertaken by Civil and General Construction, Queenstown. As this company was already located on-site at the time, completing construction of a major sewer for Grahamstown Municipality, considerable cost-advantages accrued to this simultaneous construction of the AIWPS project. The company waived Preliminary and General charges and together with MBB Inc. effected numerous cost savings which enabled completion of construction within a most tightly constrained budget. These contributions were crucial to the completion of the project, but involved an extension to the original construction time estimates.

Numerous problems were experienced during construction of the plant which resulted in time losses including:

- ❑ A hard bedrock platform was encountered during the construction of the fermentation pit requiring mechanical excavation. Due to the instability of the area, explosives could not be used, and the resulting process proved time consuming;
- ❑ Heavy rains occurred during a critical stage in the construction of the facultative pond which required repairs and involved further delays;
- ❑ The HRAP had to be constructed on an unstable landfill area and site stabilisation required unforseen additional work;
- ❑ The decision to build a gas canopy and an access bridge was not included in the original plans and was added later;
- ❑ It was also decided to add a Petro System onto the plant to enable experimental evaluation of this process together with the AIWPS (WRC ProjectK5/713). This added an additional time requirement;
- ❑ Certain design details relating to fittings and operation of the system were received from Oswald Green only during the course of 1995.

The pilot plant was finally commissioned in February 1996 with the first raw sewage pumped into the fermentation pit on 27th February, 1996. Start-up and monitoring plant operation ran through to February 1997.

4. PROCESS DESIGN

4.1 GENERAL

The design rationale and calculations presented in the following sections were provided by Oswald Green and provided the basis for the conceptual plan for the construction of the AIWPS Plant at the GDW.

The AIWPS Plant was to consists of one PFP containing a single fermentation pit, two identical HRAP, two ASP, and several under-drained Algal Drying Beds (ADB). Although constructed as a demonstration unit, it should be sized to provide credible performance data, suitable for use in engineering scale-up requirements. Each unit of the design would be in scale with the other elements of the system in order to illustrate the AIWPS technology, and to accurately reflect its actual performance.

It was decided that the AIWPS Plant at Grahamstown should have the capacity to treat the liquid wastes of 500 person equivalents (PE). An average water consumption and disposal per capita of approximately 150 $L.day^{-1}$ was assumed. Accordingly, the design flow (Q) of the Grahamstown AIWPS would be:

$$Q = 150\ L.day^{-1} \times 500\ PE = 75,000\ L.day^{-1} = 75\ m^3.day^{-1}$$

The ultimate Biochemical Oxygen Demand (BOD_{ult}) of human excreta is assumed to be 80 grams BOD_{ult} per person per day. So the organic loading rate to the system (L_o) will be:

$$L_o = 80gBODult.PE^{-1}.day^{-1} \times 500\ PE = 40\ 000\ g.day^{-1} = 40\ kg.day^{-1}$$

4.2 FERMENTATION PIT

In order to ensure complete fermentation of volatile solids, and to eliminate the handling and disposal of sludge over a 20 to 30 year period, a volumetric capacity of 0.45 m^3 per capita was specified. This volume is 15 times the standard volumetric per capita capacity (0.03 m^3) used in conventional sewage sludge digesters. Consequently, the volume of the fermentation pit (V_{FP}) would be:

$$V_{FP} = 0.45\ m^3.PE^{-1}\ X\ 500\ PE = 225\ m^3$$

In order to ensure the successful separation of gas bubbles from solids, an overall depth for the fermentation pit (d_{FP}) of 4.5 m was specified. The fermentation pit was excavated in the floor of the PFP. To prevent the possible introduction of dissolved oxygen into the fermentation pit which may result from wind-induced vertical mixing, the fermentation pit should have a perimeter berm or wall. Because the plant would be relatively small, in terms of standard ponding systems, constructed vertical walls for the fermentation pit would be necessary, rather than the earth-work berms commonly used.

The walls of the fermentation pit should extend 3.0 m below the base of the PFP and 1.5 m above its bottom. Where the PFP would be 3 m deep, the top of the fermentation pit berm wall would be 1.5 m below the pond water surface. This vertical clearance would allow for installation of a submerged gas collector should biogas recovery be required.

At a volume of 225 m^3 and a depth of 4.5 m, the area of the fermentation pit (A_{FP}) will be:

$$A_{FP} = V_{FP}/d_{FP} = 225 \text{ m}^3/4.5 \text{ m} = 50 \text{ m}^2$$

If the fermentation pit is circular, the radius of the fermentation pit (r_{FP}) will be:

$r_{FP} = (A_{FP}/3.14)^{1/2} = 4$ m; and the diameter will be 8 m. ($\pi = 3.14$)

To calculate the construction costs, the surface area of the fermentation pit walls ($A_{FP\ walls}$) must be determined:

$$A_{FPwalls} = 3.14 \text{ x } 8 \text{ m x } 4.5 \text{ m} = 113 \text{ m}^2.$$

As calculated above, the internal floor area of the cylindrical fermentation pit will be 50 m^2.

The hydraulic residence time of the fermentation pit (θ_{FP})will be:

$$\theta_{FP} = V_{FP}/Q = 225 \text{ m}^3/75 \text{ m}^3.\text{day}^{-1} = 3 \text{ days}$$

The upflow velocity is an important consideration in the design of in-pond fermentation pits and an overflow rate of 2 m per day or less will permit the settling and removal of helminths and other parasite ova from the waste stream. The upflow velocity (V_{upflow}) may be calculated as:

$$V_{upflow} = Q/A_{FP} = 75 \text{ m}^3.\text{day}^{-1}/50 \text{ m}^2 = 1.5 \text{ m.day}^{-1}$$

This upflow velocity serves to confirm the sizing of the fermentation pit design, and adds a 25% margin of safety.

Given the cylindrical shape of the present fermentation pit, it was suggested that the fermentation pit walls be constructed of pre-cast concrete blocks with vertical steel rebar set approximately 0.6 m on centre. The rebar should be approximately 1.6 cm in diameter. The fermentation pit walls should be constructed on a poured concrete base slab in which the vertical steel rebars are bent at a 90° angle and tied to the slab grid of horizontal rebar set 0.4 m on centre.

4.3 PRIMARY FACULTATIVE POND

This element of the system surrounds and covers the fermentation pit. To calculate the volumetric capacity of the PFP, assume a maximum hydraulic residence time (HRT) (θ_{PFP}) of 20 days. In this case, the volume of the PFP (V_{PFP}) will be:

$$V_{PFP} = Q \times \theta_{PFP} = 75\ m^3.day^{-1} \times 20\ days = 1\ 500\ m^3$$

Assuming a depth of 3 m, the surface area of the PFP will be:

$$A = V_{PFP}/d = 1\ 500\ m^3 / 3\ m = 500\ m^2$$

This area will correspond to the mid depth area (A_{PFPmd}) of a PFP where sloping earthwork berms are used. As such ponds are earthwork reactors, the internal and external slopes of the berms as well as the berm widths must be considered when calculating pond dimensions and surface area requirements. Assuming that the inner slope of the PFP is 3:1, the radius of the PFP at the waterline (3.0m water depth) will be 4.5 m greater than the radius at mid-depth (1.5 m water depth) and 9 m greater than the radius at the pond bottom (0.0 m water depth). The mid-depth diameter (r_{md}) will be:

$$r_{md} = (A_{PFPmd}/3.14)^{1/2} = 12.6\ m$$

The diameter of the PFP at the water surface will be 34.2 m and the diameter at the bottom will be 16.2 m. Assuming a 0.5 m freeboard and berms that are 4 m wide at the crown, the diameter from the centre of the opposite berms will be 41.2 m. The area at the water surface (A_{PFPws}) of the PFP with internal berms sloped 3:1 will be:

$$A_{PFPws} = 3.14 \times (17.1\ m)^2 = 919\ m^2$$

Note: If a 2:1 inner slope is used, the area of the PFP at the water surface will be:

$$A_{PFPws} = 3.14 \times (15.6\ m)^2 = 765\ m^2$$

In order to check the surface loading rate of the PFP, assume a conservative BOD_{ult} removal in the fermentation pit of 50%. Therefore, the remaining BOD entering the overlying PFP would be:

$$40\ kgBOD_{ult}.day^{-1} \times 0.5 = 20\ kgBOD_{ult}.day^{-1}$$

Using the 912m^2 surface area resulting from a 3:1 inner slope, the organic loading rate to the PFP (L_{PFP}) will be:

$$L_{PFP} = 20\ kgBOD_{ult}.day^{-1}/912\ m^2 = 0.022\ kgBOD_{ult}/m^2/day^{-1}$$

Using the 765 m^2 surface area resulting from a 2:1 inner berm slope, the organic loading rate to the PFP (L_{PFP}) will be:

L_{PFP} = 20 kgBOD$_{ult}$.day^{-1}/765 m^2 = 0.026 kgBOD$_{ult}$.m^{-2} .day^{-1}

Either of these surface loading rates is acceptable.

While a 2:1 inner berm slope is more difficult to construct, the steeper slope substantially decreases the required fill. For example, a pond constructed on level land having berms with inner slopes of 3:1 and outer slopes of 2:1 will have a berm volume of 45.5 m^3 per linear metre of berm. In contrast, if the inner slopes of the berm are 2:1 and the outer slopes 1.5:1, then the berm volume will be 35.4 m^3 per linear metre of berm, a saving of approximately 10 m^3 per linear metre of berm.

Regardless of the slopes specified, the water line of the PFP should be protected with a surface that will prevent unsightly weed growth, erosion from wave action and mosquito breeding. Heavy plastic liner material, such as a high density polyethylene liner, or concrete are preferable. Rip-rap with stones or broken concrete is not recommended due to the difficulty of cleaning and its harbourage of weeds, insects and rodents.

Water transferred from the PFP to the HRAP should be drawn from approximately 1 m below the surface in order to avoid carry over of floating solids. Floating solids should instead be removed using a scum ramp located on the downwind side of the pond. The scum ramp should have a slope of approximately 6:1 near the waterline.The horizontal location of the transfer structure should be 90° from the prevailing wind direction and about 5 m from the edge of the waterline.

4.4 HIGH RATE ALGAL PONDS

Two HRAP would be constructed to provide both for the routine operation of the system and its use as an experimental facility. The HRAP were designed on the basis of organic loading and solar energy. The maximum COD of the Grahamstown sewage is around 1000 mg.L^{-1}. Assuming a conservative BOD$_{ult}$ in the influent sewage of 800 mg.L^{-1} and assuming a conservative combined removal in the fermentation pit and primary facultative pond of 60%, the HRAP influent BOD$_{ult}$(I_{HRAP}) will be:

I_{HRAP} = 0.4 x 800 mg.L^{-1} BODult = 320 mg.L^{-1} BOD$_{ult}$

In order to oxidize the influent organic load, the concentration of algal cells (C_c) in a HRAP expressed in mg.L^{-1} is normally set equal to the influent BOD. Again this rule of thumb includes a safety factor as algae produce net oxygen through photosynthesis in an amount between 1.6 and 1.9 times their cell dry weight mass. Using an empirically derived formula, the depth of light penetration (d_L) expressed in centimetres can be determined by dividing 6 000 by the influent BOD:

d_L = 6,000 / 320mg.L^{-1} BOD$_{ult}$ = 18.75 cm

The depth of light penetration is normally 2/3 of the optimal HRAP depth, so the optimal depth of the HRAP (d_{HRAP}) will be:

d_{HRAP} = 3/2 x 18.75 cm = 28 cm.

The other expression of this empirical equation is:

C_c = 6 000d/$_L$ = 6 000/18.75 cm = 320 mg.L^{-1}

Assuming average solar insolation for Grahamstown of 300 cal.cm^{-2}.day^{-1} and a photosynthetic efficiency of 3,5%, the optimal hydraulic residence time (θ) in days can be calculated by the following equation:

$hC_c = SAF\theta$

where h is the heat of combustion of algae in cal.mg^{-1}; S is the solar energy flux expressed in cal.cm^{-2}.day^{-1}; A is the area occupied by 1l in the HRAP expressed in cm^2; and F is the photosynthetic efficiency. Therefore:

θ = hC_c/SAF = (5.5 cal.mg^{-1} x 320 mg.L^{-1}) / [300 cal.cm^{-2}.day^{-1} x (1000 cm^3/28cm) x 0.035]

θ = 4,7 days

For experimental purposes, the depth of the HRAP would be studied at ± 8cm intervals, and ± 1,25 day intervals of HRT. Because there may be a shortage of water, the following range of HRAP depths were considered; 18 cm, 26 cm and 34 cm. The range of HRT would be 3.5 days, 4.75 days and 6.0 days. Therefore, the worst case maximum flow (Q_{max}) will occur when the depth is 34 cm and the HRT is 3.5 days:

Q_{max} = (d_{max} x A_{HRAP})/θ_{min} = (0.34 m x 500 m^2)/3.5 days = 47.57 m^3.day^{-1}

The control HRAP would be operated uniformly at the mean depth and mean HRT and its control flow (Q_{ctr}) would be:

Q_{ctr} = (d_{ctr} x A_{HRAP}) / θ_{ctr} = (0.26 m x 500 m^2)/4.75 days = 27.35 m^3.day^{-1}

Therefore the worst case total flow ($Q_{Twc)}$ will be:

Q_{Twc} = Q_{max} + Q_{ctr} = 48.57 m^3.day^{-1} + 27.35 m^3.day^{-1} = 75.92 m^3.day^{-1}

This Q_{Twc} is greater than the design flow of 75 m^3.day^{-1}, so the intervals in HRAP depth may be changed to ± 7 cm giving a range of depths of 18 cm, 25 cm, and 32 cm. Now the worst case maximum flow (Q_{max}) will be:

Q_{max} = (0.32 m x 500 m^2)/3.5 days = 45.71 $m^{3.}$$day^{-1}$

The worst case total flow (Q_{Twc}) will be:

Q_{Twc} = Q_{max} + Q_{ctr} = 45.71 m^3.day^{-1} + 27.35 m^3.day^{-1} = 73.06 m^3.day^{-1}

This Q_{Twc} is less than the 75 $m^3.day^{-1}$ design flow and is therefore acceptable. So the final design depth variations will be 18 cm, 25 cm and 32 cm, and the design variations in HRT will be 3.5 days, 4.75 days and 6.0 days.

Recirculation of water from the HRAP back to the PFP should be carried out only when the water temperature in the HRAP is greater than the water temperature in the PFP, otherwise oxygen might be introduced into the fermentation pit by the sinking of colder (denser) oxygenated water. Recirculation was not factored into the flows calculated for the HRAP, but recirculation is recommended in order to provide an oxygen-rich surface layer to the PFP to prevent release of odours. Clearly the amount of recirculation will change the flows into the HRAP, and this amount must be incorporated into the final design.

The overflow velocity ($V_{overflow}$) is calculated:

$$V_{overflow} = d_{HRAP}/\theta = 0.28 \text{ m}/4.7 \text{ days} = 0.0596 \text{ m.day}^{-1}$$

Therefore, the organic surface loading rate for the HRAP (L_{HRAP}) will be:

$$L_{HRAP} = 0.0596 \text{ m.day}^{-1} \text{ x } 320 \text{ mg.L}^{-1} \text{ BOD}_{ult} = 19.1 \text{ gBOD}_{ult}.\text{m}^{-2}.\text{day}^{-1}$$

This organic load would require 19.1 g oxygen.m^{-2}.day^{-1}. Assuming that algae produce 1.6 times their dry weight cell mass of dissolved oxygen, the necessary concentration of algae will be:

$$C_c = 19.1 \text{ g0}_2.\text{m}^{-2}.\text{day}^{-1}/1.6 = 11.9 \text{ g.m}^{-2}.\text{day}^{-1}$$

An algal productivity of 11.9 g.m^{-2}.day^{-1} is realistic.

Because there will be two HRAP, an even flow to each HRAP will be:

$$Q_{HRAP} = Q/2 = 75 \text{ m}^3.\text{day}^{-1}/2 = 37.5 \text{ m}^3.\text{day}^{-1}$$

At this flow the maximum area required for each HRAP (A_{HRAP}) will be:

$$A_{HRAP} = Q_{HRAP's}/V_{overflow} = 37.5 \text{ m}^3.\text{day}^{-1}/0.0596 \text{ m.day}^{-1} = 629 \text{ m}^2$$

It turns out that this area would not be adequately supplied with sewage during certain experimental flows, and accordingly the area of each HRAP (A_{HRAP}) must be decreased to 500 m^2:

$$A_{HRAP} = 500 \text{ m}^2$$

Assuming a channel width of 4 m, the channel length (CL) will be:

$$CL = A_{HRAP}/4\text{m} = 500 \text{ m}^2 = 125 \text{ m}$$

It is advisable for hydraulic reasons to minimize the number of channel turns, and thus the HRAP would have only 2 channels, each 62.5 m long.

4.5 ALGAL SETTLING PONDS

Once microalgae have grown in the HRAP they should be removed from the treated effluent prior to discharge. Microalgal growth in the paddle-mixed HRAP form well-developed flocs which tend to autoflocculate and/or bioflocculate during mixing, and settle rapidly when they are introduced into a quiescent settling pond. Typically more than 50% of the algae will settle in a period of hours. Since the settled floc is essentially green algal biomass, from which readily degradeable organic matter is removed, it is resistant to decomposition and can be stored in the settling units for several weeks, and possibly even months. It should then be removed and may be dried on sand beds or be used as concentrated (3%-5% solids) liquid fertilizer. Removal is accomplished by decanting the supernatant liquid in the settler down to the sediment, and then removing the concentrated biomass with a slurry pump. For continual settling and ease of harvest, and because two HRAPs are to be used, two ASP units each with a 0.5 day HRT would be provided. The bottom of the settling units must be sloped to enhance movement of the slurry toward the slurry pump. The slurry is pumped from a pit at the inlet end of the unit which is sloped to attain best slurry removal. In the small-scale ASP unit the slurry can be moved to the slurry pump by hand with a "squeegee".

Assuming no loss or gain from precipitation or evaporation, the volume of each settling unit will be ½ of the daily flow into each HRAP:

$$V_{SU} = 0.5 \text{ x } 37.5 \text{ m}^3 = 18.75 \text{ m}^3$$

Assuming an average depth of 1.5 m, the area of the settling units (A_{SU}) will be:

$$A_{SU} = 18.75 \text{ m}^3 / 1.5 \text{ m} = 12.5 \text{ m}^2$$

With a length to width ratio of 6 to 1, the width of each settling unit (W_{SUs}) will be:

$$W_{SU} = (12.5 \text{ m}^2/6)^{½} = 1.443 \text{ m}$$

Where the width of the settling units was 1.4m the length of the settling units (I_{SU}) will be:

$$I_{SU} = 12.5 \text{ m}^2/1.4 \text{ m} = 8.92 \text{ m}$$

Using 9 m for the length, the ratio of length to width will be:

$$1{:}w = 9 \text{ m}/1.4 \text{ m} = 6.43$$

This length to width ratio is acceptable.

4.6 ALGAL DRYING BEDS

Drying a 3% to 5% solids slurry of algae usually requires 1 to 2 days in an underdrained sand bed. To estimate the quantity of algae to be dried on the sand beds, assume an average dry weight algal productivity in the HRAP of 15 $g.m^{-2}.day^{-1}$ and assume a 50% harvest from the settling units. So for two 500 m^2 HRAP, the dry weight harvest of algae (H) will be:

$$H = 0.5 \text{ x } 15 \text{ g.m}^{-2}.\text{day}^{-1} \text{ x } 500 \text{ m}^2 \text{ x } 2\text{HRAP} = 7\,500 \text{ g.day}^{-1}$$

Assuming that the algae slurry is concentrated to 3% solids, the maximum daily volume (V_{AS}) will be:

$$V_{AS} = 7\,500 \text{ g.day}^{-1} /0.03 = 250\,000 \text{ g} = 250 \text{ kg} = 0.25 \text{ m}^3.\text{day}^{-1}$$

Assuming that an algal slurry 5 cm deep will be pumped into the sand bed surface, the daily area (DA_{ADB}) required will be:

$$DA_{ADB} = 0.25 \text{ m}^3.\text{day}^{-1} /0.5\text{m} = 5 \text{ m}^2.\text{day}^{-1}$$

Allowing 7 days for drying and removal of the algae cake, the total sand bed area (TA_{SB}) will be:

$$TA_{ADB} = 5 \text{ m}^2.\text{day}^{-1} \text{ x } 7 \text{ days} = 35 \text{ m}^2$$

These calculations indicate a total sand bed area of approximately 35 m^2. Another rule of thumb for the area of sand beds is 10% of the total HRAP area. The latter method would result in a total sand bed surface area of 100 m^2. To compensate for the disparity in these two estimates, and to accommodate for the possibility of a lower solids concentration in the algal slurry, the total ADB (TA_{ADB}) would be 40 m^2:

$$TA_{SDB} = 40 \text{ m}^2$$

Four underdrained sand beds should be constructed each with a surface area of 10 m^2 and dimensions of 2 m by 5 m. These should provide adequate drying area for any contingency.

5 CONSTRUCTION DESIGN

Completion of the conceptualisation stage in the planning of the AIWPS Plant, and development of the process design outlined above, led to confirmation of the design parameters for construction of the Plant at the GDW. Following the conceptualisation stage in the planning of the AIWPS Plant to be constructed at the GDW, and based on the process design rationale outlined above, the following parameters were established as the basis for the final construction of the plant.

5.1 DESIGN PARAMETERS

5.1.1 General

Person equivalent	500
Flow rate per person	150 $L.day^{-1}$
Total flow rate	75 $m^3.day^{-1}$
Organic loading (max COD)	1000 $mg.L^{-1}$
Max BOD_{ULT}	800 $mg.L^{-1}$
Loading rate (BOD_{ult})	40 $kg.day^{-1}$

5.1.2 Fermentation Pit

Hydraulic retention time:	3 days
Upflow velocity:	1.5 $m.day^{-1}$
Depth:	4.5 m

Biogas collection by submerged polyester strengthened PVC tent above fermentation pit.

5.1.3 Primary Facultative Pond

Hydraulic retention time:	20 days
Volume:	1500 m^3
Surface area:	840 m^3
Overflow take-off:	1 m below surface

5.1.4 High Rate Algal Pond

Surface are:	500 $m^2.pond^{-1}$
Water depth:	30 cm
Hydraulic retention time:	3.5 to 6 days
Linear velocity:	20 to 40 $cm.second^{-1}$

5.1.5 Algal Settling Pond

Hydraulic retention time:	0.5 day
Algal settling:	50% to 80%
Algal slurry concentration:	3% to 5% solids

5.1.6 Algal Drying Bed

Surface area 10 m^2

5.2 CONSTRUCTION ASPECTS

Construction plans for the AIWPS Plant at the Rhodes University Environmental Biotechnology Field Station, located at the GDW, were prepared by Mr Peter Ellis of MBB Inc.. The final design plans are reproduced in Appendices 1 to 6 and may be referred to for additional details throughout the following discussion on the construction and commissioning of the plant.
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- ❑ Appendix 1. Drawing No.61428/201: Proposed Five Hundred Person Pilot-Scale Advanced Integrated Ponding System.
- ❑ Appendix 2: Drawing No.61428/202: Facultative Pond Plan, Sections and Details.
- ❑ Appendix 3: Drawing No.61428/204: Fermentation Pit Plan, Sections and Details.
- ❑ Appendix 4: Drawing No.61428/206: High Rate Ponds Plan, Sections and Details.
- ❑ Appendix 5: Drawing No.61428/208: Settling Units and Drying Beds Plan, Sections and Details.
- ❑ Appendix 6: Drawing No.61428/209: Paddle Wheel Mounting - Plan, Details and reinforcing layout.

The following notes and general comments were received from Oswald Green and provide valuable additional information in the implementation of the AIWPS design.

5.2.1 Hydraulic Aspects

5.2.1.1 Influent Control

Although a wastewater hydrograph (which measures Q vs. t) for domestic sewage flow will vary by several-fold during the day, it would unduly complicate investigations to attempt to simulate such a hydrograph experimentally. It should be pointed out, however, that one of the great advantages of AIWPS is that, due to the long residence times and buffer capacity, they can be safely designed based on average daily flows. Accordingly it was recommended that constant inflow to the PFP be provided. A bypass valve at the source of screened and degritted sewage near the pump outlet would permit restraint on the amount of flow going to the PFP flow control weir box. If excessive flow goes to the flow control box, it might exceed the capacity of the constant head regulator. Also the flow to the control box must be large enough to activate the constant head regulator.

5.2.1.2 Recirculation

Two positive displacement timer controlled pumps would be required for recirculation. It would be necessary to have timers in the minutes per hour range for the recirculation pumps due to the very small quantity to be pumped each hour. The head difference for recirculation required that prevention of back-flow be provided. Leak-proof back flow prevention check valves in addition to positive displacement pumps were recommended. Since recirculation pumps would only operate between 10:00 am and 6:00 pm, accurate calibration is needed. It is important that the recirculation discharge be at the surface of the PFP along the upwind side.

5.2.2 Electrical aspects

All controls with fuses or starter switches and timers should be mounted on a conveniently-located large control panel and comply with safety regulations. Since all of the motors are of fractional horsepower they can be wired with buried outdoor three wire romex or equivalent cable. Safety anti-shock interrupters must be provided on all circuits.

5.2.2.1 Location of the motor drives

1. Motors for primary influent pumps should be located at the agreed division box receiving degritted and screened sewage situated below the old screening house at the GDW.

2. Recirculation pump motors should be located near the recycle intakes. Each HRAP would have its own motorized pump with the times of pumping controlled by timers.

3. Paddle wheel motors to be located on the edge of the paddle wheel liquid fairleads (constricted side walls). Paddle wheel motors to be operated continuously at carefully calibrated speeds regulated by a controller.

4. Algal slurry is to be drawn out to the drying beds approximately every two weeks. The water above the settled algae should be decanted and pumped back to the PFP by way of the recirculation line. This would require a portable pump with variable-depth suction.

5. After decantation is complete, the settled algal slurry should be pumped to the drying beds.

6. Drainage below sand beds to be pumped into the recirculation line above the PFP recycle inlets. A portable scavenger pump to be used.

5.2.2.2 Power rating of each drive

1. Motors for the primary influent pumps should be 0.2 kW.

2. Recirculation pump motors should be 0.2 kW. timer-operated positive displacement pumps with leak-proof check valves to prevent backflow.

   Each pond to have separate independent pumps, timers and check valves. They flow into a common recirculation line that discharges on the upwind side of the PFP.

3. Paddle wheel drive motors to be 0.25 kW with 0.35 kW controllers. Each HRAP to be independently operated with motors and controllers as previously specified.

   Settling unit return will require 0.2 kW pump with manually controlled depth inlet. The pumped liquid to be discharged through a check valve into the recirculation line. This will not effect the HRT of the PFP since this will be done only between experiments.

4. Underdrainage from the sand beds should be returned to the PFP by way of the recirculation line using a float-operated 0.2 kW scavenger pump. An outlet check valve would be required to prevent backflow from the recirculation line into the scavenger pump. This volume is small and would not significantly affect the HRT of the PFP.

5.2.2.3 Level controls and flow rate meters

Levels are all determined mechanically by the calibrated position of overflow weirs. Volumes of flow to be controlled by timers regulating the time of pumping with carefully calibrated pumps and/or bypasses.

5.2.2.4 Control "pulpit" or motor control cubicle

A 1800 mm x 2400 mm x 300 mm box with hinged doors that will open fully to reveal the electrical elements inside is recommended. This box should be mounted on posts so that is about 900 mm above the ground. The box should be located for ease of access and where it is unlikely to be struck by moving vehicles. It should be located centrally at the paddle wheel end of the HRAP. This box will contain all starters switches and controllers except for the main feed pumps which should have a switch box and alternator switch located near the pumps.

5.2.2.5 Lighting requirements

The control box should be illuminated inside and have an outside high-level light. A street light should be located near the PFP for safety and for weir box inspection. Several outlet plugs should be provided for portable lights and portable pumps at the PFP side of the HRAP, and near the Settling Units, and the Algal Drying Beds.

5.2.2.6 Explosive gases likely to be present

Methane, produced at the centre of the PFP, is explosive at the level above 5% in air. The collection point for methane is at least 20 m away from any electrical motors.

Methane and other gasses will be metered and used on a semi-continuous basis or released to the open air so there will be no significant build up or long-term storage of explosive gasses. However, it should be emphasized that raw sewage is naturally corrosive due to sulphides; therefore, electrical equipment should be made of corrosion-resistant materials or located in fully-enclosed containers. Note that unprotected copper corrodes rapidly in the presence of sulphides.

5.2.2.7 Motor timer controls

Because it is desirable to have flow rates of several litres per second and because flows of waste produced by 500 persons per day are so small (0.3 to 1.5 $L.sec^{-1}$), both feed pumps and recirculation pumps simulating large-scale systems must be operated at rates near 3-4 $L.sec^{-1}$ with their total output regulated by timers that turn pumps on and shut them off. Feed pumps will require 24 hour timers adjustable for fractions of an hour. Recirculation pumps must be controlled by hour-and-minute timers in series to get the accurate recycle volume needed.

5.2.2.8 The number of starts per hour

1. Influent pumps will have one start per hour alternating between 2 pumps. The pumps should be controlled to run for a fraction of an hour depending on the required flow for the program. Generally the flow rate must exceed that to be introduced to the pond, and the excess will overflow back to the inlet to maintain a constant head on the influent metering weirs.

2. Recycle pumps will start once per hour between 10:00 am and 6:00 pm (8 $hrs.day^{-1}$). The fraction of an hour during which they run may be short and hence a minute timer in series with the hour timer may be needed for precision.

3. The paddle wheel drive motors will always be on and their speed of rotation will be controlled electrically with the specified ½ H.P. controller. Pumps other than these described above are either float activated or manual.

5.2.3 Gas Collector

It was recommend that the submerged gas collector for the Demonstration Plant at Grahamstown be fabricated using a sturdy reinforced, plastic liner material such as the 16 $ounce/yd^2$ scrim-reinforced laminated PVC fabric manufactured by Herculite Products Inc. in York, Pennsylvania. The Herculite 16-ounce "pool cover" is distributed in Europe and South Africa by ETS Lievens/Lanckman. The Herculite plastic liner was used in 1992 to fabricate the first submerged gas collected at the Richmond AIWPS and has performed well over the past several years showing no signs of deterioration or leakage.

The Herculite plastic liner consists of a 1 000 denier thread polyester scrim cloth (9 x 9 threads per square inch or approximately 3 x 3 threads per square cm) that is laminated between two 5 to 7 mm thick PVC sheets using a PVC adhesive plastisol.

To fabricate the Grahamstown submerged gas collector using Herculite pool cover or comparable plastic liner material, a template should be made. Depending on the width of the roll, 12 or more pie-shaped pieces of fabric can be cut, overlapped 5cm, and stitched together using nylon thread and 5-cm wide nylon webbing for seam reinforcement, bottom attachment, and attachment to the flotation collar. At the lower edge of each seam, the nylon webbing should be looped in order to fasten the base of the collector to the eye bolts set into the upper concrete wall of the digester. A flotation collar should be attached to the upper end of the cone-shaped collector using the nylon webbing which will extend around the flotation collar and fastened to itself in a plastic buckle. The flotation collar should be made of closed-cell polystyrene foam board approximately 18 cm tall by 30 cm wide with an inside diameter of 45 cm.

To secure the base of the submerged collector, we recommend using Dacron rope (9.5 mm diameter) to pass through the eyebolts which extend from the cylindrical concrete digester wall. We further recommend that the gas cap at the surface of the pond be fabricated using rigid PVC sheets that are cut and heat-welded into a cylinder with a hole through the centre by which the cap travels up and down on the central support column. The annular gap between the cap and the PVC pipe should be no more than 10 mm on any side. The open end of the cap should be submerged into the pond approximately 20 cm, providing a water seal and sufficient gas pressure when the cap is stationary to drive the gas through the gas line to its final end use destination. The vertical position of the surface gas cap must be fixed in order to build the necessary gas pressure.

6 CONSTRUCTION AND COMMISSIONING

The construction and commissioning of the AIWPS Plant at the Environmental Biotechnology Experimental Field Station raised numerous issues and problems which not only provide useful information in the implementation of the technology under South African conditions, but also account for the adjustment of the time-scale and outcomes of the Project K5/651. Experience with the commissioning and start-up of the plant is described here.

6.1 RAW SEWAGE SUPPLY

6.1.1 Pumping Main and Blockages

Two pumps were provided to pump raw sewage to the AIWPS site from the division box, after screening and degritting, at the head of the GDW. The pumps were to be controlled by timers to alternate on a daily basis. Construction constraints prevented the connection of the two pumps to the rising mains with the result that only one operated on a continuous basis. The rising main was 200 m long with a total head of 10 m.

Raw sewage enters a division box with a V-notch weir to measure flow. Excess raw sewage is returned to the GDW division box via a return flow line. Both rising main and return flow line are 75 mm class 4 UPVC pipe. Flow is controlled by way of Saunders valves.

The raw sewage pump delivers approximately 165 $m^3.d^{-1}$ at the AIWPS site. If 75 $m^3.d^{-1}$ is used to feed the AIWPS Plant, about 90 $m^3.d^{-1}$ needs to be returned to the GDW division box. The linear velocity and pressure in the 75 mm PVC pipe are high enough to prevent any blockages, but the 75 mm return line operates under gravity. The result is that fibre, plastic and other foreign material is entrapped in the joints of the pipe. Furthermore, due to the slow linear velocity, bacterial growth occurs inside the pipe. This resulted in the return flow line not being able to cope with the return flow and thus causing an increased overflow into the PFP. This problem was overcome by stopping the main pump and using the standby pump to reverse flow in the return flow line for about 10 minutes. The higher linear velocity scoured the pipe of foreign material and bacterial growth, and restored the desired flow rates in the return line.

6.1.2 Flow Control and Weir Calibration

The raw sewage flow control box designed by MBB Inc. and approved by Oswald Green was constructed during March/April 1995. To ensure a constant flow into the system the return flow is regulated by closing a Saunders valve to maintain a constant level at the overflow weir. Alternatively, the Saunders valve on the incoming line could be closed, but that is not desirable since it will reduce the linear velocity in the pipe and therefore the scouring action to prevent biological growth.

Flow control via the Saunders valves did not work due to frequent blockages. In July 1995 Oswald Green stated that they preferred not to use Saunders valves because no throttled valve would give constant flow due to clogging, and a change in head would ruin the accuracy of the experimental flow. They therefore sent a design for a much more reliable constant head bypass to be retrofitted in the flow control box ahead of the V-notch weir. The bypass consists of a pan 340 mm in diameter and 150 mm deep connected at the centre to the bypass line by a flexible tube. This bypass will maintain a controllable level that will vary by only a few millimetres and can be regulated by adjusting the pan height to control bypass flow and hence to attain any flow needed at the V-notch weir.

A second important change was that the V-notch as specified by MBB Inc. and approved by Oswald Green had too wide an angle and therefore would not be sufficiently accurate to regulate the small and various flows needed in the experiments. Instead a 23.5° V-notch weir as shown in Appendix 8 was recommended by Oswald Green. All the 45° weirs, were replaced by 23.5° weirs which caused a considerable delay during the commissioning period. These weirs were all calibrated at several depth levels. Calibration was effected in the old fashioned way using a bucket and stopwatch.

6.2 BRIDGE

At the inaugural Steering Committee meeting held on 21 July 1994 it was agreed that an access bridge to the centre of the PFP be constructed for research purposes. This bridge proved to be particularly useful for sampling the fermentation pit and the collection system (Figure 6.1).

Figure 6.1 Primary Facultative Pond of the AIWPS Plant, at the Rhodes University Environmental Biotechnology Experimental Field Station. The access bridge leads to the gas collection unit.

6.3 GAS COLLECTION

The gas collection canopy was fabricated using polyester strengthened PVC and supported with stainless steel wire as indicated by Oswald Green in section 5.2.3 (Figure 6.2).

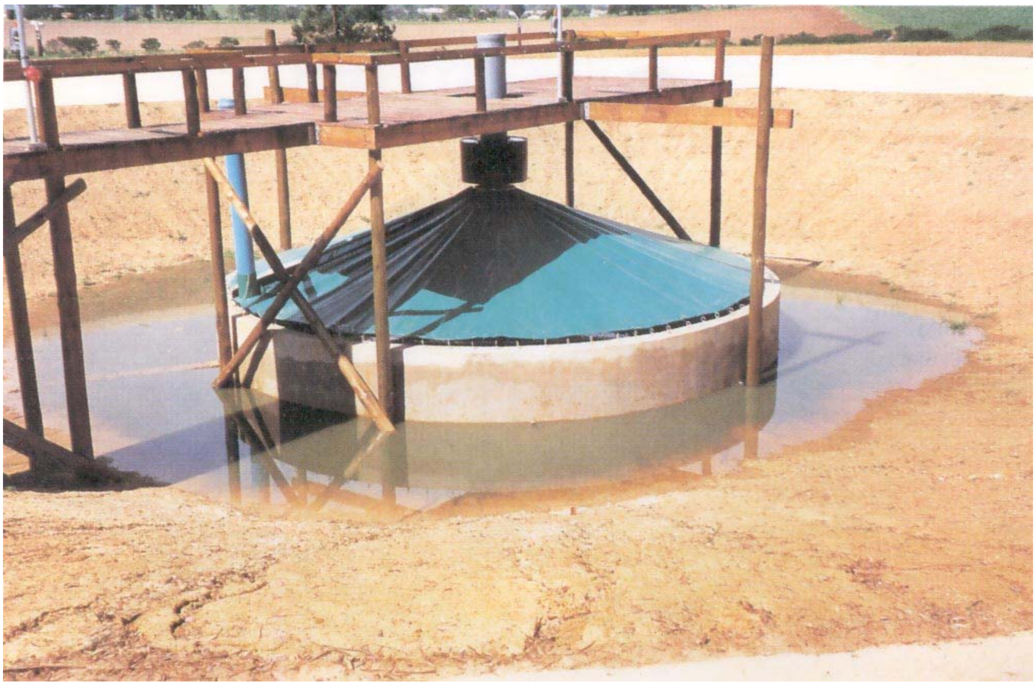

Figure 6.2 Fermentation Pit constructed inside the Primary Facultative Pond, showing the access bridge, the gas collector canopy and the collection collar.

6.4 HIGH RATE ALGAL PONDS

The HRAP, as designed (Appendix 4), had only one semi-circular wall in the centre of the raceway at each end. The semi-circle started in line with the dividing wall. On entering the raceway turn the water on the outside accelerates, with the result that when the water body enteres the straight part of the raceway, water against the outside wall moves faster than against the dividing wall. This results in a swirling effect and creates a backward movement of water against the dividing wall. Up to a third of the distance from the beginning of the dividing wall the development of a quiescent zone results in large volumes of algae settling on the bottom of the raceway.

For optimum performance a constant linear velocity is required throughout the width of the raceway. This is accomplished by dividing the water stream (while it is still flowing linearly) into four semi-circular pathways one metre before the end of the dividing wall. Only a light swirling effect is seen at the end of the innermost semi-circle pathway (Figure 6.3), and very little settling of algal flocs occurs.

Figure 6.3 High Rate Algal Pond of the AIWPS Plant, at the Rhodes University Environmental Biotechnology Experimental Field Station, showing paddle wheels and the flow path dividing walls.

6.5 COMMISSIONING

Commissioning of the plant commenced on 27th February 1996 with introduction of raw sewage into the PFP.

6.5.1 Primary Facultative Pond

In commencing start-up, raw sewage was introduced into the fermentation pit at a rate of 75 $m^3.day^{-1}$. When the sewage in the pit reached a depth of 2.2 m (i.e. 110 m^3 volume), 8 m^3 of sludge from the GDW anaerobic digesters was added on 1 March 1996, as a seed for the anaerobic fermentation. The contents were mixed by way of a submerged sewage pump for three days without the entrapment of air. During this time 55 mm of rain fell, which resulted in the water depth in the pit increasing to 3.03 m. On 4 March 1996 gas formation was observed providing evidence for the commencement of active anaerobic function.

Raw sewage was again added to a total depth of 3.5 m in the pit, at which depth partially digested sewage started to seep to the PFP through the drain holes in the wall of the pit, level with the ground in the PFP. Under these loading conditions it took 18 days for the PFP to fill and overflow.

6.5.2 High Rate Algal Ponds

While the PFP was filling, final effluent from the GDW was pumped into the HRAP. The speed of the paddle wheels was set to move the water in the ponds at linear flow velocities of approximately 30 $cm.sec^{-1}$. A geared motor with an AC invertor capable of infinite speed control was installed enabling the paddle wheel to start at very slow speeds, and accelerating incrementally to the final desired rotational speed.
For the HRAP, the starting frequency of the paddle wheel meter was slowly increased from 1 to 43.5 Hz, giving the required linear velocity (or velocity of

mixing) of ± 30 $cm.sec^{-1}$. The treatment performance of the HRAP is described in Section 8.

Figure 6.4 Algal Settling Unit in the foreground with three of the four Algal Drying Beds visible behind this unit.

6.5.3 Algal Settling Ponds

The ASP with an HRT of 12 hours produced a clear final effluent containing no settleable algae (Figure 6.4). These operated effectively from the first few days of filling and their performance is also described in Section 8.

6.5.4 Trouble-shooting

The plant commissioning phase occupied approximately 3 months. During this time numerous matters required attention including the repair of a number of minor leaks, pump failures and repairs to pipework damaged during construction. Changes had to be effected to the sewage offtake pumping point immediately after the grit trap and to the main pipeline to overcome problems of blocking which at times severely impeded flow. A repair to the gas deflector tent involved the draining of the PFP, and the construction of the HRAP semi-circular walls required the draining of the HRAP.The anaerobic pit performance proved quite unstable and required seeding from the GDW anaerobic digesters on a number of occasions to sustain appropriate loading rates.

7. OPERATION AND PERFORMANCE RESULTS

In addition to construction, the original programme for Project K5/651 had allowed a period of time for the operation of the AIWPS system, to evaluate operational performance in effecting the technology transfer function. Following the extensive trouble-shooting required during the commissioning and start-up phase, stable operating conditions were established for the system only by mid-June 1996. Although the completion date for the project was December 1996, the results reported below relate to the entire period up to February 1997, which provided the 50 week evaluation study period detailed in this report.

Since long-term operating experience would be required to support its wider implementation in South Africa, and to support IAPS development in the 'Salinity Sanitation and Sustainability' programme, it was decided that a 5-year monitoring programme should be undertaken. This was done in Projects K5/799 and K5/1073, and will be reported in 2003. The results reported here are therefore provisional findings for the initial period of operation. Wide fluctuations in certain parameters, measured during the start-up phase and prior to establishment of stable operating conditions, have been ignored and these have been reported only from week 26, from where reasonably stable operating conditions may be dated.

It should be noted that the full period required to achieve stable operation in this study would probably not apply to actual start-up conditions in a full-scale system where adequate seeding of the pit is available from the outset.

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7.1 COD LOAD

From the outset it was noted that the sewage feed to the GDW showed substantial variation in COD load. This indicated that the design assumptions regarding average loading to the AIWPS may require revision. For this reason a composite 24 hour daily sampling study was undertaken for a consecutive 30 day period. The results reported in Figure 7.1 show a variation in influent COD load between 600 and 1800 $mg.L^{-1}$ with an average of about 950 $mg.L^{-1}$. The GDW receives periodic discharges from a bucket disposal system.

During the course of the study period a number of rainfall incidents occurred during which COD levels of the sewage feed to the system fell below 100 $mg.L^{-1}$. These incidents, of not particularly high rainfall (+25 mm), had an immediate and profound effect on destabilising the operation and performance of the anaerobic pit. Given normal fluctuation and the evidently fairly large-scale stormwater entry to the Grahamstown sewerage system, regulation of COD load to the AIWPS, short of shut-down during rainy weather, proved a difficulty which has faced the study throughout the project period. Particularly high rainfall periods occurred around weeks 42 and 46 and this is reflected in the results reported below.

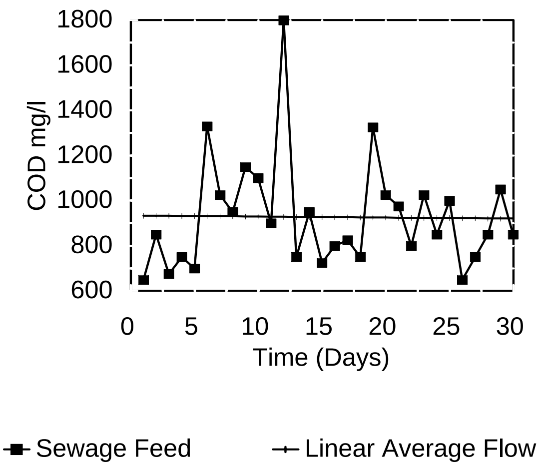

Figure 7.1 Thirty-day composite sampling average for COD sewage intake into the Grahamstown Disposal Works comparing daily feed with average flow over the sampling period.

7.2 PRIMARY FACULTATIVE POND

With the fluctuations in flow and start-up incidents described above, the anaerobic pit proved quite unstable with low pH, high volatile fatty acid (VFA) levels and a failure to accumulate a substantial sludge blanket. During week 32 the pit was re-seeded with sludge from the GDW anaerobic digesters. This resulted in the rapid stabilisation of the anaerobic processes in the pit with pH return to 6.6, VFA 78 $mg.L^{-1}$ and VFA:alkalinity ratio 1:1.54. Figure 7.2 shows VFA levels at the bottom of the pit and 1.5 m from its outflow over the second 25 week period of operation.

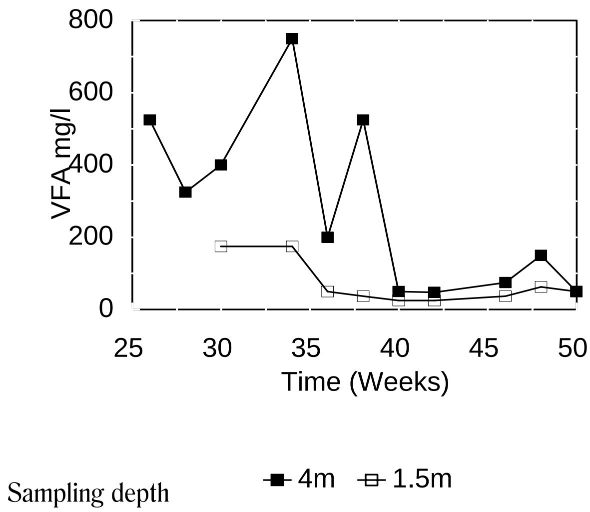

Figure 7.2 Volatile fatty acid profile monitored at depths of 1.5 and 4 m in the fermentation pit of the Primary Facultative Pond.

7.3 SYSTEM PERFORMANCE

Despite the variable performance of the anaerobic pit, the facultative pond and subsequent units demonstrated the highly effective buffering capacity of the system throughout the course of the study, notwithstanding incidents of high and low COD loading. Figure 7.3 reports COD removal across the system showing between 60% and 85% removal was consistently achieved in the PFP over the study period.

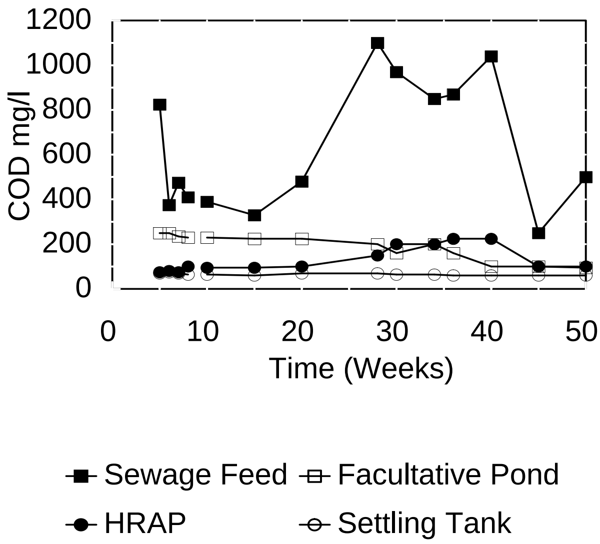

Figure 7.3 Removal of COD achieved across the full AIWPS Plant.

Figures 7.4-7.6 report nitrogen and ammonia removal across the AIWPS system.

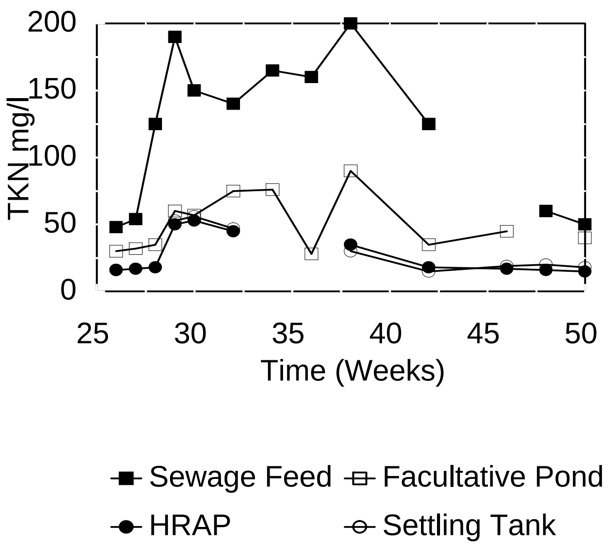

Figure 7.4 Removal of total Kjeldahl nitrogen achieved across the full AIWPS Plant.

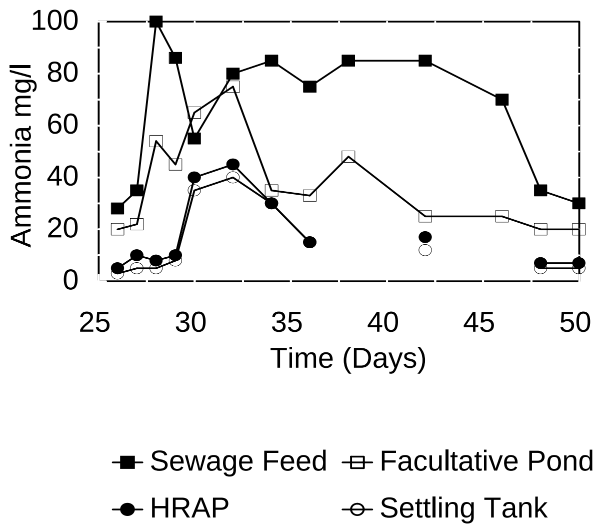

Figure 7.5 Removal of ammonia achieved across the full AIWPS Plant.

Removal of the various nitrogen fractions (both organic and inorganic) in the PFP, for stable operating periods, averaged 70% for TKN, 50%-70% for ammonia and 40%-50% for nitrate. These satisfactory removals are well within the design requirements for this component of the system.

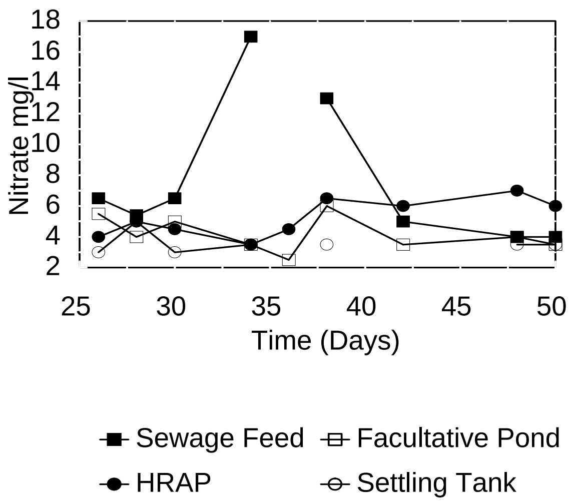

Figure 7.6 Removal of nitrate achieved across the full AIWPS Plant.

Results for phosphate removal were less satisfactory in terms of meeting special discharge standards with equivalent levels of removal achieved in the PFP and the HRAP (Figure 7.7).

Figure 7.8 reports chlorophyll a status across the AIWPS system. Recirculation of HRAP liquor to the surface of the PFP is designed to introduce algae-rich warm oxygenated water and provide a trap for odours released by the subsurface anaerobic layers. In practice the large flocs present in the HRAP liquor (+2mm) rapidly settle to the bottom of the PFP together with the predominant algae *Scenedesmus, Micractinium* and *Actinastrum* spp. The algal species able to survive and establish themselves in the upper layer of the PFP are quite different from the motile algae *Chlamydomonas* and *Euglena* spp. predominating in the HRAP. Recirculation from the HRAP was quite reliable in controlling odour release but proved relatively less effective when HRAP performance was affected in colder weather. In these circumstances populations of purple photosynthetic bacteria predominated in the PFP surface layers.

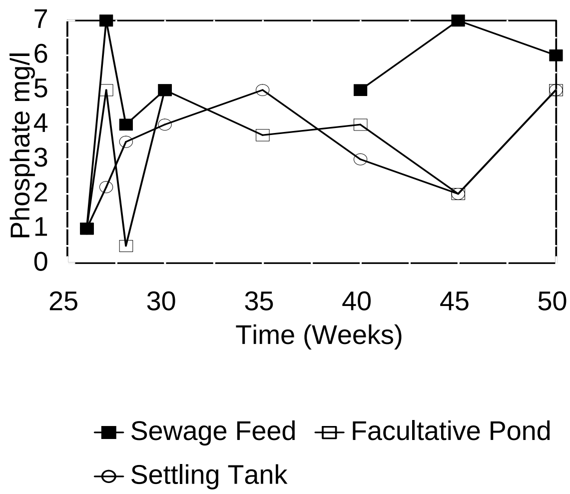

Figure 7.7. Removal of phosphate achieved across the full AIWPS Plant.

Total coliform count reduction in the PFP varied between $4.4x10^7$ - $1.4x10^9$ down to $3.9x10^5$ - $1.5x10^6$. An influent helminth egg count of 180-270 was removed in the anaerobic pit and/or the facultative pond, achieving complete removal in the PFP effluent.

While chlorophyll a levels (indicative of microalgal growth) varied quite widely from 1000μg.L^{-1} to over 4000 μg.L^{-1}, depending on temperature and sunshine hours, the average level for stable operating conditions was around 2500 - 3000 μg.L^{-1}. Figure 7.8 shows wide fluctuations in chlorophyll a levels coinciding with high rainfall conditions in weeks 42 and 46.

Elevated total COD levels in the HRAP shown in Figure 7.9 appear to exceed the load from the PFP. This is due almost entirely to the production of algal biomass in the HRAP as evidenced by rising chlorophyll a levels from week 20 to 40 (Figure 7.8), and the contribution by suspended solids (SS) as illustrated in Figure 7.10. Figure 7.9 shows that despite wide fluctuations in operating conditions the COD levels in the final effluent remained quite constant at around 60 mg.L^{-1} for most of the evaluation period. Figure 7.9 indicates that most of the residual COD remaining in the effluent is in the form of SS, and taken together with residual chlorophyll a levels around 200 - 300 μg.L^{-1}, this would be largely algal cells which have not been removed in the algal settling pond. Both the COD removal and buffering capacity of the AIWPS system are clearly impressive.

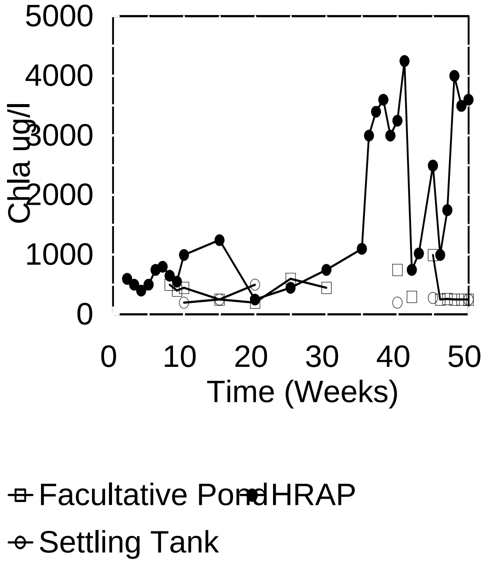

Figure 7.8 Chlorophyll a status of the various unit operations across the AIWPS Plant.

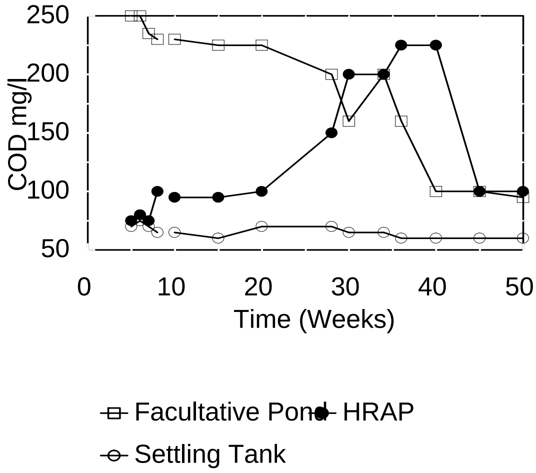

Figure 7.9 Removal of COD in the High Rate Algal Pond and in the Algal Settling Pond.

Overall nitrogen removal was efficient with final levels reduced to 3 - 4 mg.L^{-1}. Phosphate removal was less impressive, with final effluent levels averaging 3 - 4 mg. L^{-1}.

Scenedesmus, Micractinium, Pediastrum and Actinastrum spp.were the predominant algae in the HRAP. *Chlorella, Oocystis, Anacystis, Oscillatoria and Ankistrodesmus spp.* and certain diatoms occur sporadically, and mainly during the start-up period. *Chlamydomonas* and *Euglena spp.* predominate during periods of temporary pond overload. Green algae rather than cyanobacteria predominate in the system. The following ciliate protozoa were observed to predominate in the flocs: *Aspidisca*, *Vorticella*, *Paramecium*, *Opercularia* and *Stentor* spp. Total rotifer counts varied between 10 to 5000.L^{-1} and were composed principally of *Brachyonis*, *Filinia*, *Cephalodella* and *Philodinia* spp. Daphnia and copepods occurred constantly at around 5-100/l. The metazoan populations clearly play an important part in the successful operation of the HRAP.

A 4-6 log removal of coliform bacteria is effected across the system with final numbers averaging $1.2x10^3$ .ml^{-1}.

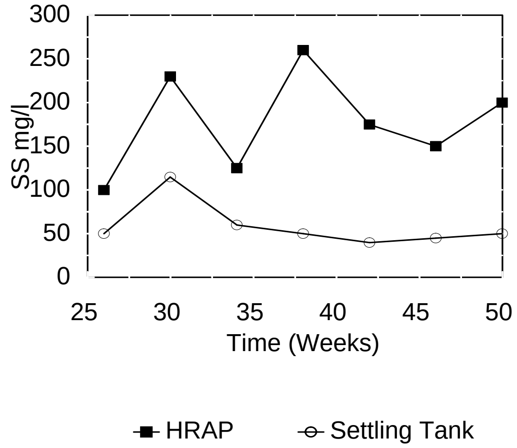

Figure 7.10 Removal of suspended solids in the High Rate Algal Pond and in the Algal Settling Pond.

The ASP operated particularly effectively with SS reduced to around 50 - 60 mg.L^{-1}. As noted above both residual COD and SS in the settler overflow is largely in the form of algal biomass. No protozoal cysts or helminth eggs were observed in the overflow. While it was recommended that algal sludge be removed after several weeks, it was found appropriate to do this on a weekly basis. The 5% solids slurry was pumped to a drying bed. A very small amount of water passes to the underdrains from the sludge and drying is largely by evaporative exposure to the sun.

The performance of the AIWPS Plant over the 25 week period of stable operation is summarised in Table 7.1.

Table 7.1 Average performance characteristics of the AIWPS plant over a 25 week period of stable operation.

(mg.L^{-1})	Influent	PFP	HRAP	Final(filtered)	General Standard
COD	950	120	150	80(60)	75
TKN	140	50	30	25(13)	-
Ammonia	70	30	7	0	3
Nitrate	7	5	4	3(2)	15
Phosphate	7	5	4	4(3)	10
Suspended Solids	-	-	150	60(0)	25
Coliforms	$4.4x10^7$	$3.9x10^5$	$5x10^4$	$1.2x10^3$(0)	$1x10^3$/100ml

7.4 ALGAL METABOLITES

Recovery of value in the form of harvested biomass was identified as one of the objectives at the outset of the project. Once algal biomass became available from the HRAP under stable operating conditions, a study commenced in mid-1996 investigating its use in feed rations for ornamental fish. This project was undertaken in the Department of Ichthyology and Fishery Science at Rhodes University under the supervision of Dr Peter Britz. MSc student Warren Pott's study "The effect of sewage-grown algae on colour enhancement in ornamental fish" was completed in 1998 and was published as an MSc thesis (Potts, 1998).

Later that year a grant application was submitted to the Development Trust to fund a Small Business Development initiative to establish ornamental fish farming projects associated with the production of treated sewage water and algal biomass in AIWPS systems. As neither of these initiatives were completed during the term of this project results will be reported in detail in follow-up WRC projects K5/799 and K5/1073 (Appendix 7).

8 DISCUSSION

The principles and viability of IAPS technology as a low-cost sewage treatment system for South African conditions has been firmly established by the Grahamstown AIWPS project.

However, during the construction and commissioning phase of the IAWPS Plant it became evident that the scaling down process highlighted aspects of the design and operation of small to medium sized AIWPS that needs more careful consideration than large plants with substantial balancing capacities.

8.1 RAW SEWAGE FEED

One of the most important claims of an AIWPS system is that it requires infrequent sludge wastage, or none at all. In the USA, AIWPS Plants have been in operation for more than two decades without any sludge being removed from the system. Apparently this is a result of the three days HRT in the fermentation pit to allow the complete digestion of all organic material. A factor that must be kept in mind is the apparent difference in characteristics of raw sewage in the USA and in South Africa. Raw sewage from small South African towns and township developments often contains large quantities of grit with the result that effluent grit removal is an important factor to be considered if desludging of the fermentation pit is to be avoided. The same applies to screening, especially plastics and non-biodegradable solids. Even after passing through standard degritting channels, large amounts of grit are pumped from the distribution chamber of the GDW to the AIWPS. These are mostly indigestible and would remain in the fermentation pit, thereby necessitating a more frequent sludge disposal.

In Grahamstown the problem could be ascribed to the manner of the operation of the mechanical screen. Screenings build up against a vertical screen causing the level of the incoming sewage to rise. After a pre-determined rise in level the mechanical screen removes the screenings with the result that flow in the degritting channel increases sharply, forwarding grit to the division box.

In applying an AIWPS system special attention should therefore be given to screening and grit removal.

8.2 BIOGAS COLLECTION

The decision to include biogas collection in the Grahamstown AIWPS was made firstly to evaluate the practicality of this operation for a small-scale plant, and secondly to determine the added value to such a system by utilising the gas for heating or electricity generation. A biogas collection system was added above the fermentation pit as a retrofit within the constraints of the existing structure.

Methane production in anaerobic digestion is characterised by the production of large bubbles of gas taking with it blobs of sludge particles. In theory as the gas rises to the surface the bubbles expand breaking loose from the solid particles which settle to the bottom. This may happen (although not always) in deep fermentation pits of 4 m or more. In the case of this plant, the lowest part of the tent was submerged 2 m below surface level, rising towards the surface at an angle of 15°. The result was that the sludge accumulated underneath the tent and slowly moved upwards towards the neck of the tent and out at the opening between the tent and the central support column. The sludge then settled outside the tent and slid down into the PFP instead of back into the fermentation pit.

The fermentation pit was re-seeded three times with the result that little active sludge accumulation occurred and biogas formation was modest.

It is evident that if biogas is to be collected, a different and more efficient gas collection system needs to be devised. The advantage of biogas collection in an AIWPS system with a body of water above the active sludge bed is that a large proportion of the carbon dioxide formed together with the methane is absorbed in the body of the water. The result is methane concentrations of up to 90% instead of the normal 72% in biogas.

8.3 PRIMARY FACULTATIVE POND

In large systems the surface layer of the PFP is kept aerobic by way of surface aeration to prevent malodours. In small systems like the Grahamstown AIWPS, the idea is to keep the surface aerobic by returning 10% of the volume of the HRAP to the surface of the PFP for 8 hours a day when the oxygen content of the HRAP is at its highest, i.e. from 10h00 to 18h00.

There are two problems with this approach. Firstly, with the applied flow regime the HRT in the HRAP fluctuates diurnally. This in itself is not a significant problem. What is more important is that settleable algae is brought back into the perimeter of the PFP where it settles and becomes anaerobic.

Secondly, the amount of oxygen introduced during the 8 hours is not sufficient to counteract malodours in the early hours of the morning. In principle, the concept of keeping the surface of the PFP aerobic with a layer of oxygen-rich algal-laden water is to be commended, but the practicality of sourcing this from the HRAP needs to be further investigated.

8.4 HIGH RATE ALGAL PONDS

The HRAP seem to work satisfactorily after the installation of the semi-circular walls at the raceway turn-around points (see Figure 6.3). This intervention was successful in preventing the settling of large amounts of biomass on the lee side of the HRAP divider wall.

8.5 ALGAL SETTLING PONDS

The ASP operated well. It was suggested by Oswald Green that the settled algae be removed every fortnight. It was found, however, that too much algae slurry builds up over two weeks and starts to become anaerobic in the sump (See Appendix 5). It was therefore decided to remove the algae once a week, producing fresh algae slurry.

8.6 ALGAL DRYING BEDS

The drying beds were of a standard design with underdrain, composed of gravel and sand, and covered with a sheet of bidum geotechnical membrane.

This elaborate and costly drying bed system was found to be unnecessary for the 5% algal slurry. The volume of water draining from the slurry was so small it could not be measured over a weir. A more simple drying system for the algae needs to be devised, since it is necessary to determine the quantity and quality of the harvested algae.

9 CONCLUSIONS AND RECOMMENDATIONS

The principal aim of the project reported here was to undertake the technology transfer operation, whereby the AIWPS process design would be constructed as a demonstration plant in South Africa, and serve as the basis for the development of IAPS technologies in an integrated management approach to saline and sanitation wastewater problems. A number of conclusions may be drawn from the programme undertaken in Project K5/651.

9.1 CONCLUSIONS

1. The three main aims of the project were realised, including the principal aim, the construction and operation of an AIWPS Plant, completed over the extended three-year period of Project K5/651.

2. The performance of the AIWPS was evaluated only over a relatively short period of time. Nevertheless, excellent COD and nitrogen removal results were observed. While individual units of the process were susceptible to shock loading and climatic effects, particularly the PFP, the system as a whole demonstrated quite remarkable buffering capacity with respect to the quality, and consistency, of the final effluent discharged. However, phosphate levels and total coliform counts were higher than acceptable and it was anticipated that improvement in these parameters will require additional attention to fully optimise operation of the system.

3. Quite severe problems were experienced in the operation of the anaerobic pit in the primary facultative pond. Besides its sensitivity to shock load conditions, especially dilutions of COD load, the gas deflector tent design, as installed, has been shown to waste sludge from the pit to the PFP rather than effect its return. As a result a substantial sludge blanket did not form in the pit, which substantially reduced its performance. Further studies on the gas collector are required.

4. A number of technology transfer activities were initiated in the course of the project activities reported here (Appendix 8). These included the opening of the AIWPS Plant as part of the IAPS demonstration and research facility, and the Rhodes University Environmental Biotechnology Experimental Field Station by the Minister of Water Affairs and Forestry, Professor Kader Asmal, on 18 April, 1997.

9.2 RECOMMENDATIONS

A number of aspects may be considered in an extension of the AIWPS technology transfer exercise, and further development of IAPS technology. The following recommendations have been made:

1. The AIWPS Plant should be operated for an appropriate period as a demonstration plant in order to facilitate the adoption of the technology into routine professional engineering practice in South Africa. It is noted that

conservatism in this area requires an appropriate time allocation be devoted to the demonstration function. Effective use of resources would be established where the plant simultaneously provides the facility for research development activities;

2. The WRC investment in the AIWPS Plant and the IAPS demonstration and research facility at Rhodes University Environmental Biotechnology Experimental Field Station should be used to pursue the development of algal biotechnology and IAPS applications in appropriate low-cost water treatment in South Africa;

3. The results from Projects K5/651, and follow-up projects K5/799 and K5/1073 should be reported together in a manual format.This would provide construction and operating design details, an appropriate period of operational experience, an accurate analysis of anticipated construction and operation costs for appropriate low-cost applications of the system. Research development results relating to the improvements effected to the technology, and a detailed literature review would be reported. This manual should also focus attention on the other applications of WRC technology developments flowing from this initiative and applied to the AIWPS and IAPS treatment of industrial effluents.

9.3 RESEARCH PRODUCTS

Given that this project concentrated mainly on the construction and commissioning of the AIWPS Plant, research products that emerged from this process have been investigated in a number of follow-up studies, including a 5-year monitoring study on the AIWPS process, undertaken in follow-up WRC Projects K5/799, K5/1073 and K5/1362. The results of these studies will be detailed in the associated WRC reports (Appendix 7).

9.4 FOLLOW-UP ACTIONS

The technology transfer initiative, and the construction of the AIWPS Plant in Grahamstown, was undertaken to demonstrate the technology under South African operating conditions, and to provide an engineering support base in the development of IAPS process applications in the treatment of saline and domestic and industrial wastewaters. A number of such application studies took place, both concurrently, and over the 5-year period following the completion of Project K5/651. These developments are noted below and in Appendix 9. Detailed results are reported in the relevant WRC reports (Appendix 7):

1. Development of IAPS in tannery wastewater treatment. A full-scale system was constructed at the Mossop-Western Leathers Co. tannery in Wellington, South Africa;

2. Development of the Independent High Rate Algal Pond (I-HRAP) as a free-standing unit operation in wastewater treatment. A number of applications of the I-HRAP were developed where the recovery of high-value algal bio-products

was demonstrated, as waste beneficiation functions of saline organic wastewater treatment operations. These include:

The *Spirulina*-High Rate Algal Pond (S-HRAP) treating meso-saline wastewaters (< 40 $g.L^{-1}$ TDIS). A 2 500 m^2 industrial-scale HRAP was constructed at Mossop-Western Leathers Co. tannery in Wellington;

The *Dunaliella*-High Rate Algal Pond (D-HRAP) treating hyper-saline wastewaters (> 40 $g.L^{-1}$ TDIS). A pilot plant was constructed at Bostswana Ash Co., Sua Pan, Botswana;

3. Development of IAPS for nutrient removal and tertiary treatment operations in domestic wastewater treatment using the I-HRAP. A pilot plant has been constructed at the Environmental Biotechnology Experimental Field Station in Grahamstown;

4. Development of IAPS for the treatment of abattoir wastewaters. A pilot-scale plant was constructed at the Cato Ridge Abattoir, South Africa;

5. Development of an IAPS hybrid system in the treatment of saline winery and distillery wastewaters. This process development was studied in a pilot plant constructed and operated at the Brennokem Pty Ltd. wine lees plant in Worcester, South Africa;

6. The Algal Sulphate Reducing Ponding Process for Acid Metal Wastewater Treatment (ASPAM), was developed for treatment of acid mine drainage wastewaters. This process involves both the I-HRAP and the IAPS applications in sulphate and heavy metal removal, and in mine wastewater neutralisation operations;

7. The development of the Rhodes Biosure Process® for the treatment of acid mine drainage (AMD) wastewaters was based on studies of complex carbon hydrolysis in the sulphate reducing compartments of IAPS treating sulphate saline wastewaters. The use of these hydrolysates as electron donor sources for sulphate reduction in mine water treatment was undertaken in this process development, and the I-HRAP was used for the final treatment and polishing of the process waters.

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12. APPENDICES

Appendix 1. Drawing No.G1428/201: Proposed Five Hundred Person Pilot-Scale Advanced Integrated Ponding System. See attached plans.

Appendix 2. Drawing No.G1428/202: Facultative Pond Plan, Sections and Details. See attached plans.

Appendix 3. Drawing No.G1428/204: Fermentation Pit Plan, Sections and Details. See attached plans.

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Appendix 4. Drawing No.G1428/206: High Rate Ponds Plan, Sections and Details. See attached plans.

Appendix 5. Drawing No.G1428/208: Settling Units and Drying Beds Plan, Sections and Details. See attached plans.

Appendix 6. Drawing No.G1428/209: Paddle Wheel Mounting - Plan, Details and reinforcing layout. See attached plans.

APPENDIX 7

WRC STUDY 'SALINITY SANITATION AND SUSTAINABILITY' - PROJECT REPORTS

The WRC study which has been summarised here developed out of a number of closely interrelated studies, undertaken for the WRC by the Rhodes University Environmental Biotechnology Group, over a 10 year period. The detailed findings associated with this work will be published separately as individual project reports. The following lists the WRC reports which cover the various investigations dealt with in the programme. The individual WRC projects under which the various studies were undertaken are listed separately below:

Report 1

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 1. Overview.

Report 2

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Wastewaters.
Part1: Meso-saline Wastewaters - The *Spirulina* Model.

(Project K5/495: A Biotechnological approach to the removal of organics from saline effluents - Part 1.)

Report 3

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Organic Wastewaters.
Part 2: Hyper-saline Wastewaters - The *Dunaliella* Model.

(Project K5/495: A biotechnological approach to the removal of organics from saline effluents - Part 2.)

Report 4

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. Part1: The AIWPS Model.

(Project K5/651: Appropriate low-cost sewage treatment using the integrated algal high rate oxidation ponding process.)

Report 5

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 2: Abattoir Wastewaters

(Project K5/658: Algal high rate oxidation ponding for the treatment of abattoir effluents.)

Report 6

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 3: Mine Drainage Wastewaters - The ASPAM Model.

(Project K5/656: Appropriate low-cost treatment of sewage reticulated in saline water using the algal high rate oxidation ponding system.)

Report 7

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 4: System Performance and Tertiary Treatment Operations.

(Project K5/799: Development and monitoring of integrated algal high rate oxidation pond technology for low-cost treatment of sewage and industrial effluents;
Project K5/1073: Extension of applications and optimisation of operational performance of algal integrated ponding systems technology in appropriate low-cost treatment of industrial and domestic wastewaters.
Project K5/1362: Development and technology transfer of IAPS applications in upgrading water quality for small wastewater and drinking water treatment systems.)

Report 8

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 5: Winery and Distillery Wastewaters.

(Project K5/1073: Extension of applications and optimisation of operational performance of algal integrated ponding systems technology in appropriate low-cost treatment of industrial and domestic wastewaters.)

Report 9

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 1: Biodesalination of Mine Drainage Wastewaters.

(Project K5/869: Biological sulphate desalination and heavy metal precipitation in industrial and mining effluents using the IAPS.)

Report 10

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 2: Enhanced Hydrolysis of Organic Carbon Substrates - Development of the Recycling Sludge Bed Reactor.

(Project K5/972: Process development and system optimisation of the integrated algal trench reactor process for sulphate biodesalination and heavy metal precipitation in mining and industrial effluents.)

Report 11

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 3: Sulphur Production and Metal Removal Unit Operations.

(Project K5/1078: Development and piloting of the integrated biodesalination process for sulphate and heavy metal removal from mine drainage water incorporating co-disposal of industrial and domestic effluents;
Project K5/1336: Scale-UP development of the Rhodes BioSURE Process® for sewage sludge solubilisation and disposal.)

Report 12

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 4: Treatment and Disposal of Sewage Sludges.

(Project K5/1169: Intermediate scale-up evaluation of the Rhodes Process for hydrolysis and solubilisation of sewage sludges in a sulphate reducing bacterial system.)

PROJECTS

The following lists the WRC Projects under which the studies in this series have been undertaken, and also the relevant reports in which the detailed results have been documented:

Project K5/410

A Biotechnological approach to the removal of organics from saline effluents.

Report: 1. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 1. Overview.

Project K5/495

A Biotechnological approach to the removal of organics from saline effluents.

Report: 2. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Wastewaters. Part1: Meso-saline Wastewaters - The *Spirulina* Model.

Report: 3. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Organic Wastewaters. Part 2: Hyper-saline Wastewaters - The *Dunaliella* Model.

Project K5/651

Appropriate low-cost sewage treatment using the integrated algal high rate oxidation ponding process.

Report 4: 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. Part1: The AIWPS Model.

Project K5/656

Appropriate low-cost treatment of sewage reticulated in saline water using the algal high rate oxidation ponding system.

Report 6: 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 3: Mine Drainage Wastewaters - The ASPAM Model.

Project K5/658

Algal high rate oxidation ponding for the treatment of abattoir effluents.

Report 5: 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 2: Abattoir Wastewaters.

Project K5/799

Development and monitoring of integrated algal high rate oxidation pond technology for low-cost treatment of sewage and industrial effluents.

Report 7: 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 4: System Performance and Tertiary Treatment Operations.

Project K5/869

Biological sulphate desalination and heavy metal precipitation in industrial and mining effluents using the IAPS.

Report 9: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 1: Biodesalination of Mine Drainage Wastewaters.

Project K5/972

Process development and system optimisation of the integrated algal trench reactor process for sulphate biodesalination and heavy metal precipitation in mining and industrial effluents.

Report 10: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.

Volume 4. The Rhodes BioSURE Process®. Part 2: Enhanced Hydrolysis of Organic Carbon Substrates - Development of the Recycling Sludge Bed Reactor.

Project K5/1073

Extension of applications and optimisation of operational performance of algal integrated ponding systems technology in appropriate low-cost treatment of industrial and domestic wastewaters.

Report 7: 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 4: System Performance and Tertiary Treatment Operations.

Report 8: 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 5: Winery and Distillery Watewaters.

Project K5/1078

Development and piloting of the integrated biodesalination process for sulphate and heavy metal removal from mine drainage water incorporating co-disposal of industrial and domestic effluents.

Report 11: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 3: Sulphur Production and Metal Removal Unit Operations.

Project K5/1169

Intermediate scale-up evaluation of the Rhodes Process for hydrolysis and solubilisation of sewage sludges in a sulphate reducing bacterial system.

Report 12: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 4: Treatment and Disposal of Sewage Sludges.

Project K5/1336

Scale-up development of the Rhodes BioSURE Process® for sewage sludge solubilisation and disposal.

Report 11: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 3: Sulphur Production and Metal Removal Unit Operations.

Project K5/1362

Development and technology transfer of IAPS applications in upgrading water quality for small wastewater and drinking water treatment systems.

Report 7: 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 4: System Performance and Tertiary Treatment Operations.

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APPENDIX 8

TECHNOLOGY TRANSFER ACTIONS

8.1 OFFICIAL OPENING OF THE AIWPS PLANT

The AIWPS Plant and the IAPS demonstration and research facility constructed at the Rhodes University Environmental Biotechnology Experimental Field Station, Grahamstown, were officially opened by the Minister of Water Affairs and Forestry, Prof Kader Asmal, on 18 April 1997. The event was attended by some 300 local people, engineers, scientists and senior government officials.

Figure A 8.1 Hon. Minister of Water Affairs and Forestry, Prof Kader Asmal handing over the keys of the plant to the Mayor of Grahamstown Cnlr. Mpahlwa. Background from left to right: Dr D Woods, Vice Chancellor Rhodes University; Dr O Hart and Prof P Rose, Rhodes University EBG.

8.2 WISA TECHNICAL TOUR

A Technical Tour to the Environmental Biotechnology Field Station and the AIWPS Plant took place during the Port Elizabeth WISA Conference, in 1996. Approximately 150 visitors attended including engineers, scientists, local government and DWAF officials.

8.3 SITE VISITS

The AIWPS Plant has been visited by over 3000 people since its opening, including scientists, engineers, municipal officials, students, scholars and the general public. It has attracted particular attention at the Grahamstown Scifest, and is regularly used for teaching students in environmental biotechnology, industrial microbiology, applied biochemistry and environmental economics.

8.4 WRC TECHNICAL TOUR

A technical tour of inspection of developments in the WRC study relating to IAPS Technology in South Africa was undertaken 24 - 26 January, 1996 (Figure A8.2). Members of the Technical Committee included: Prof C.T. Johnson (Chairman WRC); Mr P.E. Odendaal (Executive Director WRC); Mr D.S. van der Merwe (Deputy Director WRC); Mr Z. Ngcakani (Research Manager WRC); Mr J.R. Muller (Abakor); Dr A. Jarvis (Sasol Ltd.); Dr O.O. Hart (Rhodes University); Prof P.D. Rose (Rhodes University).

Sites visited included:

1. SASOL β-carotene production technical scale plant in Upington.
2. WRC/Mossop Western Leathers commercial scale IAPS plant in Wellington.
3. WRC demonstration plant IAPS sewage treatment in Grahamstown
4. WRC/Abakor demonstration IAPS plant at Cato Ridge Abattoir.
5. De Beers pilot plant for treatment of diamond wastes at De Beers Diamond Research Laboratory, Johannesburg.

Figure A 8.2 Technical tour party which undertook the inspection of WRC AIPS project installations. From left to right Prof P.D. Rose (Rhodes University); Mr D.S. van der Merwe (Deputy Director WRC); Mr Z. Ngcakani (Research Manager WRC); Prof C.T. Johnson (Chairman WRC); Mr J.R. Muller (Abakor); (Pilot); Dr O.O. Hart (Rhodes University); Dr A. Jarvis (Sasol Ltd.); Mr P.E. Odendaal (Executive Director WRC).

APPENDIX 9
APPLICATIONS OF INTEGRATED ALGAL PONDING SYSTEMS TECHNOLOGY

A primary goal of the AIWPS technology transfer exercise was that, in addition to demonstrating the technology in sewage treatment in South Africa, inputs would be made in the development of IAPS as a 'core technology' in an integrated beneficiation approach to saline and sanitation wastewater treatment. Applications of the technology were studied in the treatment of a number of industrial wastewater types. These technology development studies were undertaken in WRC projects noted below.

9.1 IAPS IN TANNERY WASTEWATER TREATMENT

Following research on the performance and operation of the tannery WSP in Wellington, and piloting of IAPS process development at Mossop Western Leathers Co., Wellington, the full-scale implementation of the IAPS process was undertaken. This involved construction of the full-scale 2 500 m^2 *Spirulina*-HRAP, and incorporated the retrofitting of ponding units in the established WSP system. These studies are detailed in WRC Report 'Integrated Algal Ponding Systems and the Treatment of Saline Wastewaters. Part1: Meso-saline Wastewaters - The *Spirulina* Model'.

The industrial-scale IAPS plant treating tannery wastewaters was officially opened by the Hon. Minister of Water Affairs and Forestry, Prof Kader Asmal, on 28 November, 1997. The event was attended by about 250 local people, engineers, scientists and senior government officials.

Figure A9.1 The 2 500 m^2 *Spirulina*-HRAP (S-HRAP) raceway, a component unit operation in the IAPS system treating tannery effluent at the Mossop Western Leathers Co., Wellington.

9.2 THE *DUNALIELLA*-HRAP AND β-CAROTENE PRODUCTION

The treatment of hyper-saline wastewaters, utilising the halophilic micro-alga *Dunaliella salina,* and linkage to β-carotene recovery as a value-added by-product of treatment, was investigated in the hyper-saline compartments of the tannery IAPS. Studies on the optimisation of β-carotene production by *D.salina* led to the development and patenting of the Dual Stage Process. Research was partly funded by Sasol Ltd., who also undertook the industrial scale-up development of the process at Sastech in Sasolburg, and technical-scale production studies in Uppington. At this time (2002) full-scale commercialisation is planned in Uppington.

Development of a *Dunaliella*-based HRAP (D-HRAP) for the treatment of hyper-saline wastewaters was scaled-up and evaluated in the treatment of organic contamination in saline carbonate brines at the Botswana Ash Co. soda ash production facility at Sua Pan, Botswana (Figure A 9.2).

Figure A9.2. The *Dunaliella*-HRAP pilot plant treating saline carbonate brines at Botswana Ash Co. Sua Pan, Botswana.

9.3 THE INDEPENDENT HRAP IN TERTIARY TREATMENT OPERATIONS

While diffuse sources of contamination due to inadequate sanitation are well described, another contributing causes of the poor quality of rural surface waters is the small sewage treatment works, handling domestic and/or industrial wastewaters. Periodic malfunction in these works is common, often due to overload and operational problems, and results in an inability to meet surface water discharge standards. Where neither plant replacement nor upgrading of the existing facility can be afforded, the problems of surface water quality may go largely unaddressed with severe consequences for downstream users.

A study was undertaken to develop the HRAP as an independent unit operation for nutrient removal. This work resulted in the development of the Independent HRAP (I-HRAP) for nitrogen and phosphate removal (Figure A 9.3), and is detailed in WRC report ' Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 4: System Performance and Tertiary Treatment Operations'.

Figure A 9.3. Pilot plant of the Independent High Rate Algal Pond (I-HRAP) unit operation for tertiary treatment and the renovation of raw water at the Environmental Biotechnology Field Station, Grahamstown.

9.4 TREATMENT OF ABATTOIR WASTEWATERS

A trend in South Africa away from centralised controlled slaughtering to small rural abattoirs has required a low-cost response to treatment of these wastewaters to deal with the diffusion of the water pollution problems. The abattoir also presents a case study for the application of IAPS as an upgradeable 'core technology', in the sustainable development context. Here the initial investment by a community in sewage treatment technology should be upgradeable as its economic development unfolds. In generating a high-strength agro-industrial wastewater the abattoir provides a practical example to evaluate the flexibility of the 'core technology' investment.

Following laboratory studies on the IAPS application in abattoir wastewater treatment, a pilot plant was constructed on-site at the Cato Ridge Abattoir in Kwa Zulu-Natal (Figure A 9.4). The results of this study are the subject of WRC Report 'Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 2: Abattoir Wastewaters'.

Figure A 9.4 The HRAP unit operation of the IAPS plant constructed at the Cato Ridge Abattoir.

9.5 TREATMENT OF WINERY AND DISTILLERY WASTEWATERS

The investigation of high organic load saline wastewater treatment using IAPS technology was extended in studies on wine lees and distillery wastewaters. The saline IAPS was evaluated as an alternative to the existing practice of disposal to land irrigation. Final disposal via evaporation ponds, and associated micro-algal production, was investigated as a basis for both environmental and social sustainability in this agro-industrial application in the rural economy. In addition to a further evaluation of the upgradeability of IAPS as a 'core technology', a specific focus of this programme involved an evaluation of the beneficiation potential in transforming these agriculturally-derived wastewaters into a resource, with downstream production of algal bioproducts providing the basis for an 'integrated wastewater resource management' approach to the problem.

These studies commenced in the EBG laboratories, and involved the use of the anaerobic baffle reactor as an initial unit pre-treatment operation to reduce the organic load fed to the IAPS. Findings were then subjected to scale-up pilot study at the Brennokem (Pty) Ltd. wine lees plant in Worcester, South Africa (Figure A9.5).

The results of this study are detailed in WRC report 'Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 5: Winery and Distillery Wastewaters'.

Figure A 9.5. Pilot plant at Brennokem Co., in Worcester, South Africa, evaluating the IAPS in the treatment of wine lees and distillery wastewaters.

9.6 THE ASPAM PROCESS

The investigation of enhanced hydrolysis of complex organic substrates present in tannery effluents, and their use as carbon and electron donor sources, supporting high rates of sulphate reduction, provided an indication that ponding systems might themselves be used as bioreactors for the biological treatment of large-volume AMD flows. While WSP technology has been developed over the past 40 years for a wide range of wastewater treatment applications little attention, if any, has focussed on the use of these systems for AMD remediation.

This application of IAPS was investigated in WRC Project K5/869: ‘Biological sulphate desalination and heavy metal precipitation in industrial and mining effluents using the IAPS’, and the use of tannery effluent and sewage sludges as effective electron donors in sulphate-salinity reduction applications was demonstrated. These studies resulted in the conceptual development of the Algal Sulphate Reducing Ponding Process for Acid Metal Wastewater Treatment (ASPAM) and are detailed in WRC report ‘ Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 3: Mine Drainage Wastewaters - The ASPAM Model’.

9.7 THE RHODES BIOSURE PROCESS®

Fundamental studies were undertaken to explain the enhanced hydrolysis of organic particulate solids and sludges in the sulphate reducing compartments of the IAPS treating high-sulphate wastewaters. Application of these findings in the treatment of AMD as optimised reactions outside the IAPS environment, and utilising sewage sludges as the carbon source, resulted in the development of the Recycling Sludge Bed Reactor (RSBR) and the Rhodes BioSURE Process®. The linkage of saline and sanitation wastewater treatment would provide a sustainable management for the AMD problem for the long periods of time over which the decanting mine waters are expected to flow. The I-HRAP was used for the final treatment and polishing of the AMD process wastewaters.

The process was scaled up and evaluated in a pilot plant at Grootvlei Mine near Springs (Figure a A9.6). These studies are detailed in WRC report ' The Rhodes BioSURE Process®. Part 1: Biodesalination of Mine Drainage Wastewaters'.

Figure A 9.6 Headgear at the No.4 shaft Grootvlei Mine with the Rhodes 'BioSURE' Process pilot plant and I-HRAP raceways in the foreground.