An Assessment of the Key Factors that Influence the Environmental Sustainability of a Large Inland Industrial Complex

Volume I: Inception Report

DEC Rogers, G Mvuma, AC Brent,
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TT 544/12

AN ASSESSMENT OF THE KEY FACTORS THAT INFLUENCE THE ENVIRONMENTAL SUSTAINABILITY OF A LARGE INLAND INDUSTRIAL COMPLEX

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Report to the
WATER RESEARCH COMMISSION

by

CSIR

WRC Report No. TT 544/12

February 2013

Obtainable from:

Water Research Commission
Private Bag X03
Gezina, 0031

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The publication of this report emanates from a project entitled: *An Assessment of the Key Factors that Influence the Environmental Sustainability of a Large Inland Industrial Complex.* (WRC Project No. K5/1833).

This report is the first in a series of five reports.

Volume I: Inception report **(TT 544/12)**
Volume II: Inventory of inland salt production and key issues for integrated cleaner production for waste salt management at the Highveld mining and industrial complex **(TT 545/12)**
Volume III: Development and assessment of technological interventions for cleaner production at the scale of the complex **(TT 546/12)**
Volume IV: Governance assessment **(TT 547/12)**
Volume V: Linking technologies to governance **(TT 548/12)**

ISBN 978-1-4312-0365-9
Printed in the Republic of South Africa

ACKNOWLEDGEMENTS

The research results presented in this report emanated from a project funded by the Water Research Commission entitled:

"An assessment of the key factors that influence the environmental sustainability of a large inland industrial complex"

The authors wish to thank the following people on the Reference Group for their valuable contributions during the project:

Dr V Naidoo	Water Research Commission
Mr K Cilliers	National Cleaner Production Centre
Mr M Makwela	Chamber of Mines
Ms M Mofokeng	Department of Water Affairs
Mr HK Mazema	Process Optimisation and Resource Management
Mr DT Roux	Sasol Synfuels

The following individuals are acknowledged for their kind assistance and constructive discussions during the duration of the project:

Mr Godfrey Thema	Anglo Coal, New Denmark mine
Mr Johan de Korte	CSIR: Centre for Mining Innovation
Dr Peter Ashton	CSIR: Natural Resources and the Environment
Mr Brian North	CSIR: Materials Sciences and Manufacturing
Mr André Engelbrecht	CSIR: Materials Sciences and Manufacturing
Mr Mike Silberbauer	Department of Water Affairs
Mr Marius Keet	Department of Water Affairs
Dr Paul Meulenbeld	Department of Water Affairs
Mr. Walter van der Westhuizen	Department of Water Affairs
Mr Bishop Muladzi	Department of Water Affairs
Ms Flora Mamabolo	Department of Water Affairs
Ms Joyce Lekoane	Department of Water Affairs
Mr Dirk Hanekom	ESKOM
Mr Johan Janse van Nordwyk	ESKOM, Tutuka
Mr Boet Conradie	Harmony Gold Evander
Mr Robert Gilmour	Harmony Gold Evander
Dr Gail Nussey	Sasol Mining
Ms Tholeka Mafanya	Sasol Mining
Mr Bert Botha	Sasol Mining
Mr Gerrit Putter	Sasol Mining
Mr du Toit Roux	Sasol Synfuels
Mr D Smit	Sasol Synfuels
Dr Trevor Phillips	Sasol Research and Development
Dr Martin Ginster	Sasol Resources

The researchers that were involved in this project, in no specific order, are listed below:

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EXECUTIVE SUMMARY

The key factors affecting environmental sustainability of a large industrial complex have been identified by a review of the scientific literature, Council for Scientific and Industrial Research (CSIR) reports and news media on water management in specific inland industrial complex areas. These are:

- Scarcity of clean water supply in the medium to long term. There is increasing pressure on clean water supply as a result of challenges experienced with water treatment and growth in demand both for industrial and socio-economic development. An increase in demand for the provisioning of clean water also increases the demand on sanitation services to millions of un-serviced households. Development of large new industrial and mining projects which require water for coal washing, and mineral processing further aggravates the issue. Although the effects will be felt nationally, the focus of the problem is in the Crocodile-West Marico and Olifants Water Management Areas (WMAs). Growth in water supply will continue until about 2012 due to charging of Phase 1 dams of the Lesotho Highlands Water Project but this will be taken up by organic growth (See Section 3.6.1).
- The shortage of supply will result in increased costs as well as reuse. Reuse via treatment of the polluted inland water storage supply requires the installation of additional water treatment technologies. These are in more expensive per unit water output and require additional laboratory testing facilities to control quality. As a result of the SA energy crisis, costs of raw water can be expected to double as the result of a fivefold increase in cost of any new electrical power used for water pumping. Low energy reverse osmosis water treatment technologies are being commercialized with energy costs in the range of 4 to 8 kWh per m^3.
- Increased water treatment and extension of use to contaminated groundwater aquifers will result in more inland waste salt. Current research is on binding of salts in ash from ESKOM. At this stage of the project, there is uncertainty of long-term stability of waste storage of water soluble salts. It is not feasible to release these into the water system, long term stable storage or transport to the sea is required.
- Short- and long term build-up of salts in surface water supply for downstream water users is an ongoing concern. The post mine-closure decanting of acid mine drainage (AMD) is not being handled well by the authorities. It is likely that the quantities will increase to very large amounts (Section 3.7) in the medium term.
- South African objectives and commitments to climate change mitigation negotiations are currently based on reductions in CO_2 emissions. There is a long term linkage between water availability, sustainable development, and energy. South Africa's medium term industrial development plan is to use more coal from the unexploited but fractured coal fields in the Crocodile-West Marico WMA. Increasing carbon emissions from long-term pumping and water/wastewater treatment for fossil fuels will be an aspect of sustainability that will not be addressed in this project. But the net effect for resource managers will be increasing costs as the cost of carbon is factored into South African industrial development (See Section 3.7).
- Regulatory standards and policies on waste release into the water system have been assigned the main barrier to sustainable development. Eutrophication is attributed mostly to too high levels of phosphates (as Total P) in the effluent of wastewater treatment. Microbial pollution in surface and groundwater are placing more pressure on authorities to address issues of potable water supply and sanitation. Surface and groundwater in 85% of the Free State and large areas of Mpumalanga must be considered unsafe for human consumption, unless tested in a laboratory. Mortalities as a result of poor quality ground and surface water are reported.
- New and unknown toxic effects are expected as a result of the challenges in providing clean drinking water. These include previously exotic risks from blue green algae, anaerobic metal

hydroxide dissolution/suspension, anaerobic metal sulphides suspensions, and infectious organisms.

In selecting the case study area for this project, a database of industrial complexes has been developed (See Appendix A). A shortlist of complexes (See Table 8: Shortlist of inland industrial complexes) was derived based on and a set of specific selection criteria (See Section 3.9).

A multi-criteria decision assessment approach has identified the Secunda complex as the proposed primary case study area for this project. A benefit of choosing this complex is the research opportunities associated with options for water supply and waste disposal in two WMAs and the availability of data to support the research. Another benefit is the opportunity to transfer the learning from this case study complex to new industrial complex developments i.e. the Waterberg complex. This is discussed in more detail in Section 3.9. Inland mining and industrial complexes that were considered for this study include:

- Witbank-Ferrobank (coal mining, processing, stainless steel, power generation);
- Middelburg (coal mining, power generation);
- Secunda (coal mining, gold mining, power generation, synthetic fuel production, chemical production [organic and inorganic], and coal and gold ore processing, urban industry, and irrigation based agriculture);
- A new complex in the Waterberg coal field (coal mining, power generation, synthetic fuel production, chemical production [organic and inorganic], and coal washing, and urban industry);
- Steelpoort/Burgersfort (Palladium group metals and chrome mining and mineral processing/beneficiation, Ferrochrome arc smelting, and the expansion of water supplies to 500 000 un-serviced households).

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ABBREVIATIONS

COD	Chemical Oxygen Demand
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism (now re-named DEA)
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry (now re-named DWA)
EIA	Environmental Impact Assessment
ESKOM	Electricity Supply Commission
GDP	Gross Domestic Product
IDZ	Industrial Development Zone
kWh	Kilo Watt hour
LCA	Life Cycle Assessment
LHWP	Lesotho Highlands Water Project
m^3	cubic metre (equivalent to 1 000 litre)
MAP	Mean Annual Precipitation
MFC	Middleburg Ferrochrome Columbus
MMC	Manganese Metal Corporation
Mt/a	Million metric tonnes per annum
MWh	Mega Watt hour
NCPC	National Cleaner Production Centre
NEMA	National Environmental Management Act (Act No 107 of 1998)
NERSA	National Energy Regulator of South Africa
NRE	National Resources and the Environment operating unit of the CSIR
NWA	National Water Act (Act No 36 of 1998)
P	phosphorous
RQO	Resource Quality Objective
RWB	Rand Water Board
t	tonne (metric)
ToR	Terms of Reference
TSS	Total Suspended Solids
UCT	University of Cape Town
UKZN	University of Kwa-Zulu Natal
UNEP	United Nations Environment Programme
USD	United States Dollar
WMA	Water Management Authority
WRC	Water Research Commission

TERMS AND DEFINITIONS

Industrial Ecology	Industrial ecology seeks to apply the knowledge of systems in nature to the design and operation of industrial activities, to achieve integrated and sustainable relationships between the natural world and industry.
Pollution (NEMA)	The National Environmental Management Act (1998) defines pollution as any change in the environment caused by substances, radio-active or other waves or noise, odour, dust or heat emitted from any activity, including the storage or treatment of waste or substances, construction and the provision of services, whether engaged in by any person or an organ of state, where that change has an adverse effect on human health or well-being or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future. National Water Act, (1998) defines pollution as the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it – (i) Less fit for any beneficial purpose for which it may reasonably be expected to be used; or (ii) Harmful or potentially harmful – (a) To the welfare, health or safety of human beings (b) To any aquatic or non-aquatic organisms (c) To the resource quality; or (d) To property
General Waste (DEAT, 2007)	waste that does not pose an immediate hazard or threat to health or to the environment, and includes- (a) domestic waste; (b) building and demolition waste; (c) business waste; and (d) inert waste.
Waste (DEAT, 2007)	means any substance, whether or not that substance can be reduced, re-used, recycled and recovered- (a) that is surplus, unwanted, rejected, discarded, abandoned or disposed of; (b) which the generator has no further use of for the purposes of production; (c) that must be treated or disposed of; or (d) that is identified as a waste by the Minister by notice in the Gazette, and includes waste generated by the mining, medical or other sector but- (i) a by-product is not considered waste; and (ii) any portion of waste, once re-used, recycled and recovered, ceases to be waste;
Waste disposal facility (DEAT, 2007)	means any site or premise used for the accumulation of waste with the purpose of disposing of that waste at that site or on that premise;
Waste management activity (DEAT, 2007)	means any activity listed in Schedule 1 or published by notice in the Gazette under section 19, and includes- (a) the importation and exportation of waste; (b) the generation of waste, including the undertaking of any activity or process that is likely to result in the generation of waste;

	(c) the accumulation and storage of waste; (d) the collection and handling of waste; (e) the reduction, re-use, recycling and recovery of waste; (f) the trading in waste; (g) the transportation of waste; (h) the transfer of waste; (i) the treatment of waste; and (j) the disposal of waste;
Waste minimisation (UNEP, 2005)	The concept of waste minimisation was introduced by the U.S. Environmental Protection Agency in 1988. In this concept, waste prevention approach and its techniques are defined as on-site reduction source reduction of waste by changes of input raw materials, technology changes, good operating practices and product changes. Off-site recycling by direct reuse after reclamation are also considered to be waste minimisation techniques, but have a distinctly lower priority compared to on-site prevention or minimisation of waste. Currently, waste minimisation and pollution prevention terms are often used interchangeably. Pollution prevention means not generating waste in the first place by reducing it at the source. Waste minimisation is a broader term that also includes recycling and other means to reduce the amount of waste which must be treated or disposed of.
Cleaner production (UNEP, 2005)	The continuous application of an integrated preventive environmental strategy to processes, products, and services, to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society. Specifically for: *Production processes*: Cleaner Production results from one or a combination of conserving raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process; *Products:* Cleaner Production aims to reduce the environmental, health and safety impacts of products over their entire life cycles, from raw materials extraction, through manufacturing and use, to the 'ultimate' disposal of the product; and *Services*: Cleaner Production implies incorporating environmental concerns into designing and delivering services”.

1 INTRODUCTION

The terms of reference for this project spell out the general objective as follows: "Assessing the key factors that influence the long term environmental sustainability of an inland industrial complex, the potential synergy for reuse of waste products, and opportunities for implementing integrated technological solutions". The CSIR responded to this solicited proposal through a consortium to execute the project.

1.1 Research consortium

The consortium was constituted as follows:

CSIR

- Natural Resources and the Environment with responsibility for governance and coordination of stakeholders, natural systems ecology and effluent waste management, water quality, systems management, and industrial ecology.
- Materials Science and Manufacturing with responsibility for coordinating development of inventories, chemicals and process engineering and cleaner production, waste minimization, systems management, and industrial ecology.

Universities

- University of Kwa-Zulu Natal: Chemical Engineering, Pollution Research Group with responsibility for a component of Life Cycle Assessment (LCA) for Cleaner Production and Waste Minimization. This includes the assembly of the waste inventories and calculations for minimization of waste using a new model.
- University of Cape Town: Chemical Engineering took the lead on Life Cycle Assessment (LCA) for cleaner production with new Technologies. The team took overall lead on the application of LCA to a new technology assessment.

1.2 Industry and stakeholders

Industry and stakeholders who were not part of the project team, but whom were important resources for the project were identified from the industrial complex that was identified (see Section 3.9 for details on the selection of the industrial complex). Stakeholders that were identified are:

- SASOL Synfuels and Sasol Mining. A proposal for collaboration, via a non-disclosure agreement was drafted under the leadership of Dr Martin Ginster.
- ESKOM had contacts in place with UKZN via an existing project on saline waste disposal.
- Evander Gold Mines
- Govan Mbeki Local Municipality
- Mpumalanga Provincial Government: Directorate of Pollution and Waste
- Department of Water Affairs
- The Catchment Management Agency
- The National Parks Board of South Africa.

The possibility of participation by an NGO was also investigated by the governance experts. The roles of the research team and institutions in the project are summarised in Figure 1 below.

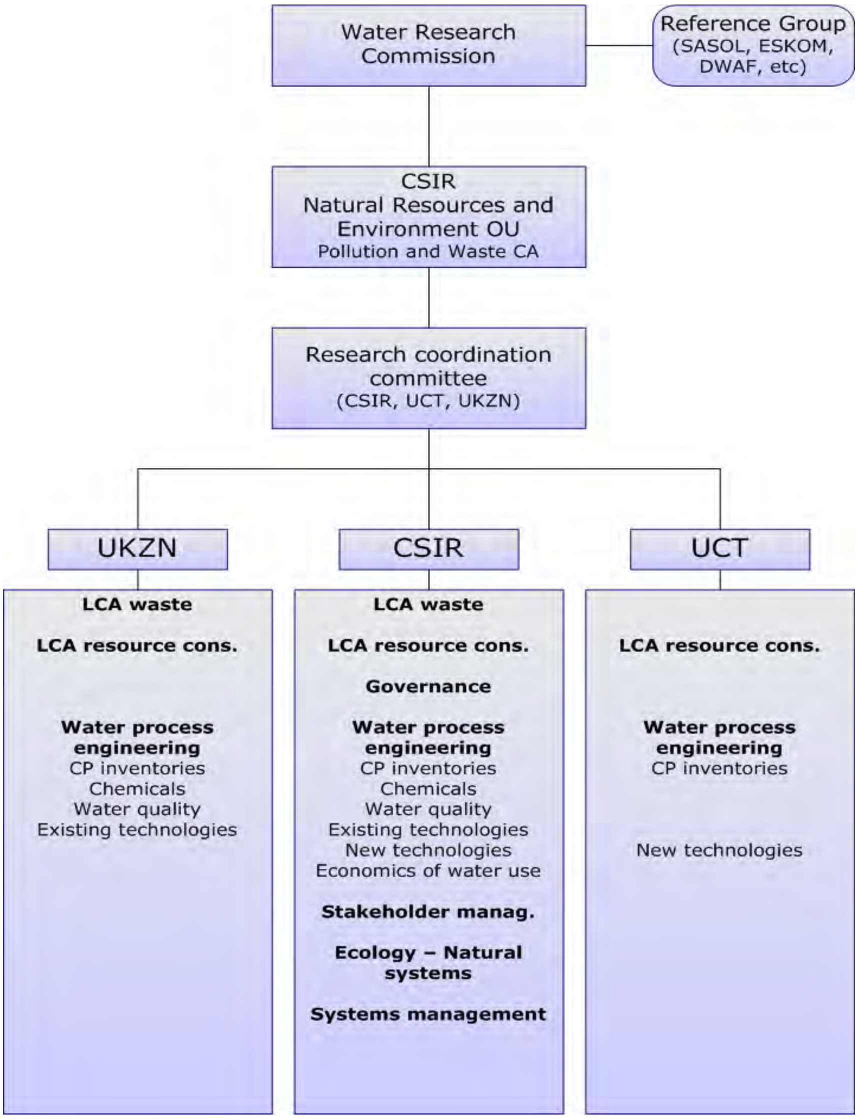

Figure 1: Project execution diagram

2 BACKGROUND AND PURPOSE

Large inland industrial complexes contribute significantly to the South African economy and provide opportunities for social and technological development. Their environmental sustainability is of critical importance in supporting the Millennium Development Goals (SA-DoH, 2005), the Long Term Mitigation Strategy (SA-DoH, 2005; DEAT, 2008a), and the government objectives for economic growth. A current concern of industry and the authorities in South Africa are the mechanisms for maintaining long-term sustainability of the inland industrial complexes. This is where the future mineral and energy wealth of the country is to be found. The two key factors are security of water supply both in terms of quality and quantity. These large complexes generate large quantities of wastewater, solid waste and gases (millions of tonnes per year). The waste streams must be managed in such a way that it does not pollute the environment, especially the water resources.

There are two levels of complexity. The first is the physical and biosphere complexity where multiple feedback loops can result in unstable ecosystems. The second is the social complexity where numerous stakeholders with conflicting economic perspectives and interests compete for the same water resource base. One of government's roles is to construct an institutional system that will ensure long term sustainability of productive social, industrial and ecological systems.

The barriers to industrial complex sustainability are discussed in Section 3.3. Barriers identified in previous South African studies on industrial eco-efficiency include protection of intellectual and commercial interests. These barriers result in the inability of industry to disclose waste stream components; survival of a complex firm being based on continuity of production with priority over adjustment of processes to minimize waste; local government incentives to maintain industrial pollution so that taxes and penalties provide revenue to pay for salaries and uneconomic services to indigent residents (UNIDO, 2004); and lack of coordination and logistical bottlenecks (CSIR-NRE, 2008).

Within the broader context, this project can be viewed as of national importance to South Africa in two ways. First, industrial ecology is in relative terms, a new emerging area of research; the concept is of interest to South African industry. A benefit is the ability to develop local skills and awareness in the stakeholders and the research consortium. Secondly, is the importance of the National Environmental Management: Waste Act, 2008 (RSA, 2008) which takes an integrated approach to Waste Management. Regional waste management plans are to be coordinated by the province. Aspects include waste avoidance, waste minimization, reuse and recycling, and minimization of integrated environmental impacts. Therefore, this research is a vehicle to inform both government and industry of options and scenarios for integrated pollution control, remediation of ecological systems that are currently dysfunctional, and protection of the sustainable yield in the remaining functional systems.

3 PROCESS FOLLOWED TO SELECT THE INDUSTRIAL COMPLEX

This section provides an outline of the process that was followed to select the industrial complex to be studied during the course of this three year project.

A six stage process has been followed:

1. The terms of reference of the proposal have been interpreted in the context of the national policy, and concepts used to describe waste minimization and cleaner production, and a review of the meaning of industrial ecology in the South African context.
2. The current and projected status of water flows and pollution of water flows has been reviewed so as to understand the main problems with environmental sustainability of industrial complexes located in the South African inland water systems.
3. The key factors affecting environmental sustainability were defined in terms of water availability, long term pollution and the associated problems and cost.
4. The assumptions and terms of reference are analysed and allocated within a research framework. The expected needs of industry, authorities and stakeholders are accommodated within the profile of the research consortium.
5. An initial set of industrial complexes is prepared using a nominal group technique with the governance and cleaner production groups. Selection criteria are identified and a shortlist is prepared by elimination for the main criteria. Final selection is based on a multi-criteria decision analysis.
6. Key stakeholders are identified and initial contacts are made with initial discussions of the key factors affecting the environmental sustainability.

3.1 Objectives and Aims

The main objective is to do an assessment of the key factors that influence the long term environmental sustainability of an inland industrial complex. Sub-objectives for the project are:

1. Compile a comprehensive inventory of input, output and on-site storage of products and waste within selected inland industrial complex(es);
2. Evaluate the environmental sustainability of current practices with respect to water use efficiency and pollution of water systems as they relate to the compiled inventory;

3. Assess the potential synergy within the complex for cleaner production opportunities by reusing water and waste with integrated technologies; and
4. Identify barriers pertaining to governance issues (regulatory) and cleaner production strategies that impede on implementation of synergistic reuse options and integrated technical solutions.

These specific objectives provide a foundation for the rationale of the project.

3.2 Rationale

It is hypothesized that economic health and prosperity of South Africa are associated with a few large and strategic inland industrial complexes. These complexes are located in close proximity to mining areas. Being nodes of economic growth, it is imperative that they generate wealth in a sustainable way. Equally important, these complexes are often major water consumers in a water-scarce South Africa (DWAF, 2004a). In addition, these complexes are major sources of pollution. The pollution potential of these complexes negatively impacts on their long-term sustainability as well as other socio-economic activities that affect the economic health of South Africa.

Mining and industrial processing activities inevitably generate large quantities of waste. Environmental and economic risks associated with current and long term potential releases of these wastes into the environment, have been recognized for many years. With expansion of the mining and industrial activities and with modern regulatory frameworks, South Africa requires practical solutions encompassing economic, ecological and social equity. The practices of storing waste on site and de-facto in closed and water filled mines, results in major environmental threats. The concept of zero-effluent discharge through storing waste on site for recycling is acknowledged as good practice. However, long term storage without a technically or economically feasible recycling option, is not considered good practice. In addition, practices of incineration of waste and trapping of gaseous emissions which can be acknowledged as good practices can result in transfer of waste from one environmental medium to another, without necessarily contributing to the sustainability of the environment.

Application of cleaner production principles is another way of ensuring the sustainability of an industry. The cleaner production hierarchy (DEAT, 2005) is illustrated in Figure 2 and is described as the following steps:

- Avoid waste production;
- Minimize waste quantities;
- Reuse waste streams;
- Recycle for another production process; and
- Safe disposal within the receiving capacity of the environment.

The diagram illustrates how raw materials, energy and ecosystem services can be reused, but only raw materials can be reprocessed using recycling technologies.

The holistic approach advocated in cleaner production can be seen in an integrated technical and regulatory approach to water and waste management in a large industrial complex. Examples of in-principle solutions are:

- Waste products from one unit may be used as raw materials for another unit;
- Co-treatment of waste from several units may result in lower environmental impact; and;
- Targeted state of an ecosystem can be used to set release times and quantities of wastes so that cumulative and synergic effects of pollution and resource depletion are avoided and higher service levels are available from the ecosystem.

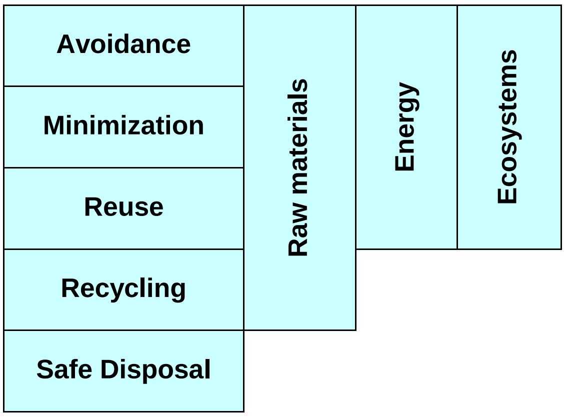

Figure 2: Hierarchical approach to resource usage (DEAT, 2005)

The case study approach has the advantage of making the research more relevant. The disadvantage is the risk of limited scientific generalization (Yin, 1989). The research approach is to base the design of the methodology on existing knowledge management frameworks of relevance to the case study in South Africa. These include the status of industrial ecology in South Africa (Brent et al., 2008), the application of saline indicators in life cycle assessments of water pollution in South Africa (Leske and Buckley, 2004a; Leske and Buckley, 2004b; Leske and Buckley, 2003), and a decision making protocol for establishing desired state in riverine systems in South Africa (Rogers and Bestbier , 1997).

3.3 Industrial ecology in South Africa

3.3.1 Advancing industrial ecology in South Africa

The South African review on industrial ecology by Brent et al. (2008) discusses the means to advance the concepts of industrial ecology in South Africa. It is argued that the concepts may best be advanced through the application of industrial symbiosis strategies both at local and regional level. Three different stages in the evolution of industrial ecology initiatives for brown field sites have been conceptualised, namely: regional efficiency, regional learning, and the sustainable industrial district (Brent et al., 2008). A selection stage precedes these three stages in the case of green field sites. At the selection stage, the actors that will form the core of the socio-technical system are selected. This selection can involve criteria related to the perceived process of sustainable development in a specific context.

3.3.2 Synergy in industrial ecology

The life cycle of industrial ecology can be expressed in terms of phases in time and the type of relationship between organisations in an area (Brent et al., 2008); these are often interconnected. South Africa still finds itself in the birth and growth life cycle phases, with some informal and formal networks, and mostly in the regional efficiency stage, although regional learning has been occurring in certain instances due to, for example, the establishment of waste minimisation clubs and the increase in cleaner production initiatives.

3.3.3 Setting boundaries for industrial ecology

A number of obstacles to initiation and management of an industrial ecosystem have been noted, these include:

- Company concerns with regard to propriety or confidential information;

- Negotiating balance of payment;
- Reluctance on the part of business to be involved in inflexible contractual commitments that do not relate directly to their core activity, i.e. guaranteeing a waste stream for a contractual period;
- Supervision and operation of co-treatment facilities; and
- The complexity of managing the wastes produced by the companies.

There is an additional barrier in South Africa in that there is no institutional support via legislative and economic to drive industrial symbiosis. As a result of these and the inexperience of the authorities there is no clear understanding of or guidance as to the responsibilities of the parties associated with the waste streams. Five mechanisms are proposed to promote industrial symbiotic approaches (Brent et al., 2008):

- Working through public-private partnerships, e.g. between local authorities who operate treatment facilities and landfill sites, industries who discharge problem waste to these facilities and sites, waste companies who specialise in waste re-use and recycling, and national government that develops legislative guidelines and evaluate performance;
- Using the South African National Cleaner Production Centre (NCPC) to develop and assist with the implementation of appropriate technologies and procedures for industrial symbiosis;
- Use of trading platforms to link waste generators and the waste re-users and recyclers;
- Introducing funding mechanisms, particularly to enhance and support the exchange of low value commodities; and
- Linking waste minimisation clubs, waste exchanges and future industrial ecological parks and zones.

3.3.4 Setting boundaries in ecosystems

The boundaries for an industrial complex can be understood using the concepts of sustainable supply of resources from nature as well as industrial efficiency in the reuse and recycling of waste (DEAT, 2005).

The geo-physical boundary can therefore be seen as the ecosystem boundary that it supplies the raw materials to, including the industrial complex and provides a long term stable absorptive capacity by which pollutants are converted into resources for an ecosystem that is acceptable to man. Figure 3 illustrates the recycling, reuse, and natural conversion systems in the production and consumption cycles of industry and society.

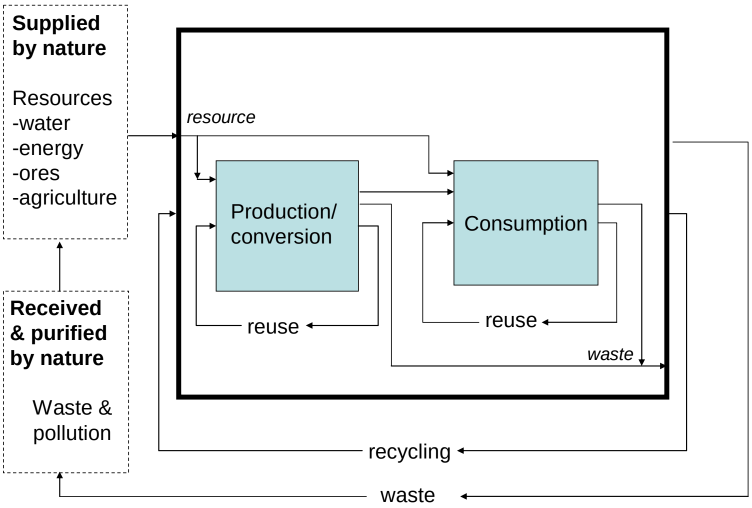

Figure 3: Flow of natural resources into the production and consumption systems, and flow of waste and pollution into nature (DEAT, 2005)

3.4 Availability and distribution of water in South Africa

The average rainfall in South Africa is about 497 mm/annum, that is, about half the world average of 860 mm/annum (DEAT, 2006). The geographical distribution of rainfall and the subsequent availability of water for supply is highly variable, with the eastern and southern parts of the country receiving significantly more rain than the northern and western regions with more than 60% of the river flow in South Africa arising from a mere 20% of the land area (Basson et al., 1997). Of specific significance is the highly seasonal and variable occurrence of rainfall over virtually the entire country.

The inland water resources comprise rivers, dams, lakes, wetlands and groundwater. South Africa, however, has no major rivers of a globally comparative scale. The largest river in the country is the Orange River, which carries less than 10% of the water flowing down the Zambezi River, the closest major river in Southern Africa (Basson et al., 1997).

3.4.1 National Water requirements

Most of the metropolitan and industrial growth centres in South Africa have been developed around mineral deposits and harbour sites that are remote from the major river courses (Basson et al., 1997). Some irrigation developments are also located sub-optimally in regions where there is low water use efficiency. The result of this development scenario is the exceedences of natural availability of water in 16 of the 19 WMAs, i.e. 90% of South Africa's area. To meet these developmental needs, extensive interbasin transfers of raw and potable water have been developed. The principle is to supply areas with water deficits from areas with water surplus (Basson et al., 1997).

South Africa relies mostly on surface water resources (rivers and dams) to provide water to users. Generally these water resources are highly developed with about 497 major dams with an approximate total storage capacity exceeding 32 400 Mm^3, which is about 66% of the total mean runoff of c. 49 000 m^3/annum. This includes about 4 800 Mm^3/annum draining from Lesotho into South Africa and a further 500 Mm^3/annum draining from Swaziland to South Africa (DWAF, 2004a). The main dams and interbasin transfers in the country are illustrated in Figure 4.

3.4.2 Sector water requirements

There is a large variation in water requirements across the country. Each sector of the economy has its own needs in terms of quantity, quality, temporal distribution and assurance of supply. This is illustrated in part by the summary of the water requirements as at the year 2000 in Table 1.

Table 1: Water requirements for the year 2000 (DWAF, 2004a)

Sector	Demand Mm^3/annum	Comment
Urban	2 897	Includes the component of the reserve for Basic Human Needs at 25 litres/person/day
Rural	574	Includes the component of the reserve for Basic Human Needs at 25 litres/person/day
Mining and bulk industrial	755	Mining and bulk water supply that are excluded from urban systems
Power generation	297	Includes water for thermal power generation only.
Irrigation	7 920	
Forestation	428	Quantities refer to impact on yield only.
Total	**12 871**	

A comparison of requirements with return flows shows that much of the water use is consumptive use, with usable return flows estimated as follows: from rural settlements (0%), irrigation (9%), urban (33%) and mining/bulk (34%) (DWAF, 2004a).

The Department of Water Affairs has calculated water deficits for 16 of 19 water management areas (WMA) and over 90% of the country area (DWAF, 2004a). Water transfers are used extensively within and between the WMAs.

Two large surpluses in WMA yields are taken to eliminate the largest deficits. These are transfers from the Senqu (Lesotho) and from the Thukela to the Upper Vaal. The sustainability of this transfer system is the main link in the sustainability of the national industrial heart of South Africa. The most recent data from the Department of Water Affairs (DWAF, 2002; DWAF, 2004b; DWAF, 2004c) are based on measurements of consumption and return flows between 1995 and 2000. The Lesotho Highlands Water Project and the Rand Water Board have more recent data which is discussed in Section 3.6.1. In some areas large portions of the population do not yet receive clean piped water or sanitation services (DWAF, 2004a; CSIR-NRE, 2008). Economic development increases demands in cities and from industry and mining (DWAF, 2004a). Irrigation demand is the largest water user (see Table 1). Lower Orange WMA is the largest irrigation user, in part due to low cost of water, high evaporation rates, and irrigation technologies. Trends in growth in irrigation are not clear to this study; the Department of Water Affairs reports collapse of some irrigation schemes and planned new schemes (DWAF, 2004a). The Department of Water Affairs and Catchment Management Agencies are responsible for balancing water demand with available yields.

The United Nations Environmental Programme reports that South Africa will move from a “fresh water stressed” to a “fresh water scarce” country with a 850 m^3/capita availability by 2025 (UNEP/GRID-Arendal, 2008). Economic growth (and growth in water requirements) is expected to be substantially higher in the larger urban and industrialized areas than in rural areas (DWAF, 2004a).

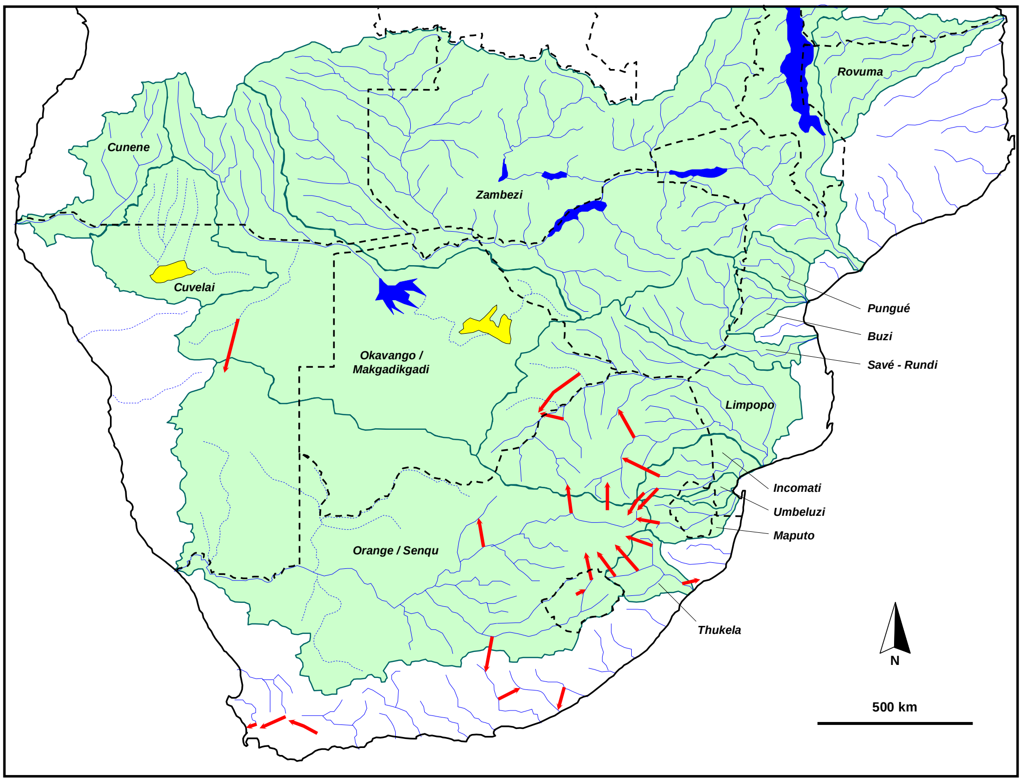

Figure 4: Main dams and interbasin transfers in Southern Africa (Ashton, 2008b).

3.5 Environmental sustainability of large inland water management areas

Measurements of environmental sustainability of water use by industrial complexes has been proposed by the Water Research Commission (in the Terms of Reference) to be primarily water use efficiency, and the potential to pollute water systems. This approach to industry sustainability has been adopted in the National Cleaner Production Strategy (DWAF, 2003; DEAT, 2005), and follows many years of research in waste minimization by the Department of Water Affairs and the Water Research Commission during the 1980s and 1990s. Reports are available in the "Natsurv" series, e.g. in the Red Meat Sector (Stephan, Roberts and Kirsten, 1989). Benchmarks are provided for water use per unit output. These are used for increasing performance, setting national standards and comparison with international trading partners. The approach is used internationally for technology performance assessments (EU, 2008), and applied in operating permits for waste release.

While benchmarks are useful for technical and economic sustainability (Rogers and Brent, 2008), the measurement of environmental or ecological sustainability requires measurement standards for the receiving environment. A South African protocol for determining river water sustainability has been developed by the Department of Environmental Affairs (Rogers and Bestbier, 1997). A Desired Future State is determined by the structure, function and composition of the intended water system (Ashton, 2008b). Measurable legal criteria include international obligations, human needs, and ecological demands (these include flow profiles for example for scouring, sustaining agreed minimum ecosystems, and historical dry periods). Agreement on a desired future state can include industry, the Department of Water Affairs, and managers of ecosystems, e.g. the Parks Board. A planning horizon of 7 to 25 years is most practicable as this is a typical time it takes to get a project from concept to operation. Midpoint measurements include average annual flows, i.e. ecological limit for streams, and average annual groundwater depth (DWAF, 2004c).

Sustainability science identifies system self cleaning capacity and carrying capacity, i.e. capacity to support numbers and quantities of life forms and capacity to supply quantity and quality of water to people and ecosystems (Folke et al., 2002). In the South African water system self-cleaning capacity is low (Ashton, 2008b). The Department of Water Affairs (DWAF, 2004a) reports that long term and expensive remediation is required as the result of eutrophication due to P levels exceeding self-cleaning capacity in inland waters. The CSIR (Ashton et al., 2008) attributes this to higher levels of pollution from agriculture, industry, and urban settlements and a need to revise P release standards accordingly, and more in line with levels in other regions that are subject to multiple reuse and low recharge volumes. The consequences of reduced cleaning capacity and higher pollution loads are seen in higher disease levels (Rogers and Masekoameng, 2008) and higher costs associated with urban and industrial use (DWAF, 2003).

A less specific but widely accepted definition of sustainable development has been provided by the World Commission on Environment and Development (1987), which describes sustainable development as “development that meets the needs of current generations without compromising the ability of future generations to meet their own needs and aspirations” (Brundtland and Khalid, 1987).

A culture of inefficient and wasteful use of water seems to be common in industry to such an extent as can be seen from the large volumes of polluted industrial water decanting and causing serious pollution of natural water resources in most parts of the country.

3.6 The most affected inland water catchments

Three inland water catchment areas have been identified for an assessment of the key factors that affect their environmental sustainability. The proposed foci for assessment are on three spheres:

- industrial water use efficiency, i.e. the amount that is returned to the ecosystem,
- the quantity of water that is available from the catchment for use by the complex,
- the ability of the complex to avoid pollution releases that exceed the absorptive capacity of the water system.

The three catchments are the Upper Vaal, Upper Olifants, and Crocodile West-Marico (Figure 5, WMA’s of South Africa) where it is likely that half of the South African GDP is generated. The sectors are bulk power generation, gold, and coal mining, associated mineral beneficiation, and tertiary industries, such as the inland chemical sector, three tiers of the manufacturing industry. The services sector is now the largest contributor to GDP and Gauteng is the home for the financial and services industry. Bulk power generation is largely located in this area and contributes about 14% to GDP. Estimates for regional contribution to GDP are about 20% for Gauteng province and about 20% Upper Vaal (DWAF, 2004d).

As can be seen in Table 2 these three catchments have the following in common:

- The Water Management Area demand is greater than the yield.
- The power generation industry returns very little of the water removed from the catchment.
- Mining and industry account for about one quarter of water use. The largest use is human settlements in urban and rural locations.

On a macro scale the largest reuse of industrial and mining water is in the Upper Vaal where 84% was returned to the system by the year 2000 (DWAF , 2004d).

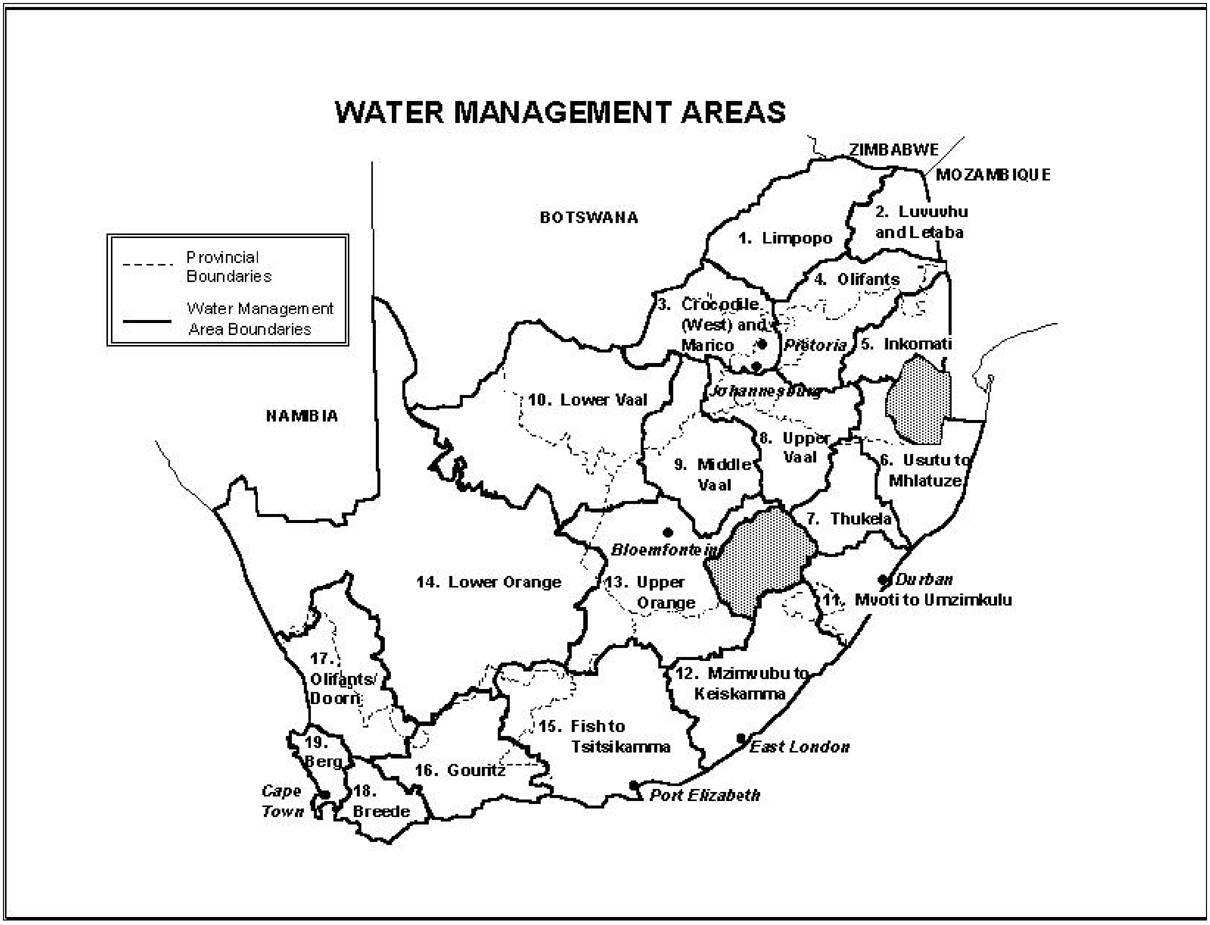

Figure 5: Water management areas of South Africa (DWAF, 2008)

Key factors affecting these WMAs are:

- The Upper Olifants River catchment comprises two secondary catchments together covering an area of ~11 464 km^2 in the headwaters of the Olifants Water Management Area (WMA). Land use is characterised mainly by coal mining, mineral processing and agricultural activities (Hobbs et al., 2008). Upper Olifants water loss to industry is dominated by large power generation capacity in the catchment (see Table 2). It also has the largest risk of low pH and heavy metal decanting as acid mine drainage (DWAF, 2004b). A predicted 62 Mm^3/annum will follow working plant closure. This effluent is highly toxic before dilution, and appears to be the direct cause of the death of fish, and crocodiles in the Loskop dam.
- Upper Vaal has a high return from the mining industry. This is likely to be due to pumping from gold mines in the dolomitic areas on the west rand.
- Middle Olifants demand for new mining projects will require further transfers because the WMA demand is already exceeded. Inkomati via Upper Olifants is the likely source. Transfers from Upper Olifant are 465 Mm^3/annum.
- Steelpoort demand in 2000 was forecast to go into deficit by 2025 (DWAF, 2004b) without a plan to introduce interbasin transfers. The deficit of 34 Mm^3/annum is approximately half of the yield (62 Mm^3/annum). Possibilities of increasing reuse were identified but not confirmed by DWA in 2000 (DWAF, 2004b). Additional rural settlement demand (approximately 2 million residents) is identified as an unaccounted priority (DWAF, 2004b). Mining and mineral processing has developed since 2000 so there may be additional unaccounted demand (see Table 2). Although new dams are being constructed, e.g. the De Hoop dam, these can be expected to stabilize water supply (possibly at the cost of additional evaporation) but not to generate additional water. In the absence of definite plans, and unaccounted demand, the possibility of sustainability requiring transfers into the Steelpoort

River cannot be excluded from long term environmental planning. Upper Olifants and Inkomati are the likely sources.

- Upper Vaal has a high return from the mining industry. This is likely to be due to pumping from gold mines in the dolomitic areas on the West rand.
- Crocodile West-Marico has a high future mining and industrial demand from coal mines and power generation and possibly a new coal to liquid plant. These will have high demand on water for washing coal, heat dissipation from Rankine cycle steam generation of electricity, and for slurry disposal of ash from coal combustion and gasification 1350 m^3 water per GWh power generation (ESKOM, 2008). Raw water input into the Fischer Tropsch process is approximately 117 Mm^3/annum from Rand Water Board and coal mines (CSIR-NRE, 2008) for 7.3 Mt of synfuel production(SASOL, 2008), i.e. 16 m^3 water per tonne of synfuel. Waste generations are 151 tonnes/GWh or 0.54kg/MJ for ESKOM power generation.
- Rand Water Board transfers 1310 Mm^3/annum of water into the Crocodile West-Marico and Upper Vaal make up about half of the Upper Vaal WMA demand (Table 2). Half of this comes from the Lesotho Highlands Water Project (LHWP) (693 Mm^3/annum). The bulk (431 Mm^3/annum) of the remainder comes from Thukela (DWAF, 2004a). The sustainability of the LHWP is therefore a key component for sustainability of Upper Vaal, and Crocodile West-Marico inland industrial complexes.
- Upper Olifants transfers from the Usutu-Mhlatuze, Inkomati and Upper Vaal are required for the power generation, mining and mineral processing. Any new complex will require additional water transfers.
- Demand from residential and urban consumers is four times larger than mining and industry in the Crocodile West-Marico and three times larger in the Upper Vaal. Urban demand growth can be expected to grow with population and socio-economic development. Rand Water estimated 2.7% per annum for 2007-8 (Rand Water Board, 2007a).

Factors that affect the sustainability of water consumption are availability of supply and cost:

- Water transfers from Lesotho have grown at 4.27% per annum since 1998 (LHWP, 2005). Growth will stop when the capacity of Phase 1 is reached. This is expected to be 2012. South Africa's demand growth for that water in 2007-8 was 2.69% (Rand Water Board, 2007a). The LHWP Phase 1 will peak in 2012 at an expected 29 m^3/s, equivalent to 915 m^3/annum.
- Phase 2 of the LHWP is intended to supply c. 21 m^3/s (DWAF, 1998). The project is currently under EIA stage (Ashton, 2008a). The implementation date was initially planned at 2015. This may be delayed due to the lower-than-expected demand from South Africa (Lesotho Minister of Environment, 2008).
- Generation of hydropower from the LHWP Phase 1 has annual sales of 498 GWhrs in 2004-5. Water is gravity fed into South Africa and generates electricity on the way. In subsequent Phases the Malatsi, Ntoahae, Tsoeklie and Mashai dams will be built; see Figure 6, and electrical power will be used to pump the South African transfer up to the Katse dam (DWAF, 1998).
- Lesotho has a deficit of electricity hydro electricity will be required to pump new water supplies. Energy demand is not available for Lesotho (LHWP, 2005). An indication of the energy consumption can be found from Rand Water Board (Rand Water Board, 2007a) where pumping cost in 2007-8 is about a sixth of the cost of raw water which is the largest expense (see Table 5). Lesotho is a net importer of power and can be expected to charge South African electricity rates for water pumped for South Africa.

Note: The map shows the down stream location of the subsequent phases of the LWHP. Phase 1a and 1b provide water from the Katse, Mohale dams and Matsoku weir). Additional electricity is required for pumping and may be offset by the hydro generation at each new dam.

Figure 6: Map of the Lesotho Highlands Water Project (DWAF , 1998)

- Energy generation cost for ESKOM in 2007 is R0.13/kWh. A recent estimate of new generation costs by the University of Cape Town indicates that supply cost will increase five times (Eberhard, 2008). Factors affecting this are illustrated in Table 6.
- Primary energy from coal will increase up to ten times for the current set of suppliers as ESKOM moves to world price parity. The contribution of coal and water to running expenses is R 11.1 billion (NERSA , 2005) for total sales of R 25 billion.
- Costs for the new South African energy expansion programme over the next 5 years are estimated to be between R 400 billion and R 500 billion. Unit costs for new generation capacity electricity will be between R 0.90 and R 1.20 per kWhr.
- Cost of carbon and the time of phasing out of current power generation technology are yet to be decided. The date for peak CO_2 emissions has been set for 2025 (DEAT, 2008b). These will be associated with higher electricity charges as the old technologies are replaced or modified, e.g. carbon sequestration technology. Stern (2006) estimates of between USD 25 and USD 85 per tonne of CO_2 are equivalent to R 1 to R 3/kWh.
- It is concluded therefore that energy cost for water pumping from the Upper Vaal WMA to Crocodile West-Marico WMA will in the long-term be at least the same as the current raw water cost of Rand Water, i.e. R 1.42/m^3 (Table 5).
- Energy and water supply is complex, i.e. the availability of water affects the availability of energy, and the availability of energy supply affects water supply.

3.6.1 Summary on cost and availability of supply

Availability of water supply for inland mining complexes in the new coal mining areas of the Crocodile West-Marico WMA is dependent upon the transfer of water. In the case of the Lesotho Highlands Water Project (LHWP), additional water is not available. Normal growth of the cities and industry will use additional flows by 2012. The other source of water is the Thukela, but availability there has not been established. It seems likely that the cost of clean water will increase as the result of energy costs, increasing demand for clean water for settlements, increasing costs for water treatment as the result of eutrophication of dams.

3.6.2 Water Demand and catchment supply

Water demand for the three main regions for industrial complexes is shown in Table 2. Demand is greater than the catchment supply, so the sustainability of water consuming operations in the complex is based on sustainability of supply from outside of the catchment area. Factors to this scenario are contained in Section 3.1.4.

3.6.3 Salt management

The main problem with mining and power generation is the production of salts due to reaction of water and oxygen with sulphides in coal and mineral deposits, and from the combustion of coal to produce metal oxides that dissolve in water.

3.6.4 Low pH and acid mine drainage

Main reactions in acid mine drainage occur as the result of reactions of water and oxygen with dissolved oxygen and some microbial action result in highly corrosive and toxic decanting mine water. Large quantities are found in Mpumalanga. Low pH results in dissolution of metals with increased toxic effects.

3.6.5 High pH and ash dumps

The main reactions of ash from coal combustion are the reaction with water of metal oxides such as FeO, MnO, CaO, MgO, Na_2O, and K_2O to produce bases.

$$NaO(s) + H_2O \rightarrow Na^+(aq) + 2OH^-(aq)$$

An advantage of metal hydroxides is their relative insolubility and a high pH precipitates more toxic metals such as Cu, Mn, Ni, and Zn.

3.6.6 Chemical Oxygen Demand (COD), total P, and Total Suspended Solids (TSS)

Un-oxidized organic waste from badly operated municipal wastewater treatment works is resulting in reduced oxygen availability in streams and dams and occasional large quantities of dead fish (DWAF, 2004a; CSIR-NRE, 2008). The South African standard for PO_4 release from wastewater treatment works is 1 mg/l of total P (Oberholster and Ashton, 2008). The cumulative effect of many wastewater treatment works and natural flows in the Crocodile-West system is eutrophication of the large dams (DWAF, 2004a). These dams have large amounts of algae including blue green algae (DWAF, 2004a) and offensive odours. Some blue green algae are fatal on single ingestion to domestic animals, and an irritant to humans (Oberholster and Ashton, 2008). Long term toxic effects are expected, but treatment to potable water requires laboratory testing. Analytical tests of wastewater treatment works are a low priority due to cost (CSIR-NRE, 2008). The additional expenses such as activated carbon (Oberholster and Ashton, 2008) are not feasible in the typical local municipalities of South Africa where wastewater treatment works are not functioning. The synergistic effect of eutrophication, TSS and COD pollution results in strongly reducing environments where sulphides and odours are produced. Heavy metals can be concentrated in sediment as insoluble sulphides. This poses a risk for any sudden later change to aerobic conditions with a low pH.

3.6.7 Build up of soluble salts in inland water systems

In contrast to metals oxides, salts from the anions Cl^-, SO_4^{2-}, and F^- and cations Na^+, Ca^{2+}, Mg^{2+}, and K^+ have higher solubility at both low and high pH. In the least altered riverine systems, the dominant ions depend upon rock types (Leske and Buckley, 2003). Ca^{2+}, Mg^{2+}, and HCO_3^{2-} are the dominant with Na^+ up to 25% of the cations in the industrial regions of Gauteng, Free State, Mpumalanga, Limpopo and North West Province. The salts monitored in industrial complexes include SO_4^{2-}, and F^- which can be used as markers of industrial and mining waste

Pollution effects of salts included in Environmental Life Cycle Assessment terminology (LCA) (Leske and Buckley, 2003) are:

- Ecotoxicity due to changes in metabolism with salt concentrations
- Reduction in agricultural yield due to the reduction of water absorptive capacity when sodic soils are irrigated with relatively high content of Na, Ca and Mg.
- Industrial plant failure due to corrosion from Cl^-, SO_4^{2-}, and scaling from Mg and Ca carbonates.

Classes of endpoints for LCA have been identified as aquatic ecotoxicity, reduced agricultural productivity, material damage, aesthetics, and effects on livestock, natural vegetation and natural terrestrial systems (Leske and Buckley, 2003).

Salts are concentrated in waste streams, e.g. from raw water purification, coal and ore processing, combustion and gasification and are released when the process material comes into contact with water. Water is also used for transportation. The halides, e.g. F and Cl, are toxic at relatively low concentrations (1 ppm is a guideline limit for F) and for this reason are pollutants for agriculture and human consumption. Additions of salt fed at each usage cycle of inland waters results in an increase in concentration further down the catchment. The natural cleaning process for salts is flushing into the sea. Dry areas with low flows of clean water have the least self-cleaning capacity. Industrial applications require low salt concentrations so as to reduce deposition on heat exchangers to avoid fouling, e.g. in power stations, and reactors, e.g. Fischer-Tropsch, so they are removed from the water systems before use by industry. The concentrated salts are transported as brines and best stored as dry salts. There is currently no economic way of recycling or safe disposal of these salt concentrates in these industrial complexes. Evaporation ponds are the common waste disposal location.

Table 2: Supply and consumption of water in inland mining and industrial complexes for Upper Vaal, Upper Olifants, and Crocodile West-Marico Water Management Areas (Mm^3/annum) (DWAF, 2004d)

	Application (Outflow Mm^3/annum)								Available water (from inflows Mm^3/annum)							
WMA	**Urban/rural**	**Agriculture**	**Mining**	**industry**	**Mining & Industry**	**Power generation**	**Outflow/ transfer**	**WMA demand**	**Urban**	**Agriculture**	**Mining**	**Industry**	**Mining & Industry**	**Power generation**	**Transfers**	**WMA yield**
Upper Vaal (2000)	678	114	173	80	173	80	1379	2424	343	12	-	-	146	0	1310	2442
% Return									51%	11%			84%	0%		
Upper Olifants (2000)	99	44	-	-	20	219	82	409	34	2	-	-	4	0	171	409
% Return									34%	5%			20%	0%		
Upper Crocodile (1995)	597.1	510	118	8.9	126.9	28	21.7	1458	288.4	54.6	35	4.4	39.4	7	875	786
% Return									48%	11%	30%	49%	31%	25%		

Table 3: Sales from Lesotho to SA (2005) and purchases Rand Water Board (2007)

	Mm^3/annum	**R /annum (Million R)**	**Cost R/m^3**	**Annual flow rate m^3/s**	**% of RWB demand**	**Capacity avg. Mm^3/annum**	**Growth demand SA**	**Comment**
Supplied Lesotho to SA 2000-2005	693	857	1.23	22		610.5	4.27%	SA demand actual lower than planned for this period (LHWP, 2005). LHWP supply planned at 29 m^3/s; actual 20 m^3/s
Purchased RWB 2007	1296	1841	1.42	41.1	53.4%		2.69% (1)	SA demand growth being met by Lesotho.

Note 1: growth rate of 2.69% is much lower than population and GDP growth in Gauteng. It is not certain that this number is correct. The relationship between economic and social development and water demand growth should be investigated.
References: (LHWP, 2005), (Rand Water Board, 2007a)

Table 4: Estimated sales of water from Lesotho High Lands Water Project to 2011-2015 (Rand Water Board, 2007a; LHWP, 2005; Rand Water Board, 2007b)

	Year	Flow m^3/s	Flow Mm^3/annum
Most recent flow data	2005	22	693
First year of maximum	2012	29	915

Table 5: Rand water cost structure for potable water 2007-8 (Rand Water Board, 2007b)

Cost Input	R/1000 m^3
Raw water	1841.00
Energy	335.48
Chemicals	138.74
Variable costs	2315.23
Labour	647.36
Other	583.41
TOTAL	3545.99

Table 6: Forecast for cost of electricity for pumping using ESKOM electricity supply

Component of electricity cost	Generation and technology	Estimated cost R/kWhr	Discounted to Rand values in year	Ref.
ESKOM generation and distribution 2005	old coal/nuclear	0.1604	2005/6	(NERSA, 2006)
ESKOM generation and distribution 2007-8	old coal/nuclear	0.1945	2007/8	(Eberhard , 2008)
ESKOM generation 2007-8	old coal/nuclear	0.1300	2007/8	(Eberhard , 2008)
ESKOM distribution 2007-8	old coal/nuclear	0.0645	2007/8	(Eberhard , 2008)
ESKOM generation 2013	New coal	0.6000	2008	(Eberhard , 2008)
ESKOM generation 2013	New Nuclear	0.9000	2008	(Eberhard , 2008)
ESKOM generation and distribution 2013	New coal	0.6645	2008	
ESKOM generation and distribution 2013	New Nuclear	0.9645	2008	
Selling margin local municipality 2007 OR Tambo levy Jan 2007	old coal/nuclear	0.2628	2006/7	(Rogers and Brent, 2008)
Household purchase new coal power	New coal	0.9273	2008	
	New Nuclear	1.2273	2008	
Vat at 14%	Coal	1.0572	2008	
	Nuclear	1.3992	2008	

Note: this assumes cost of coal is static. Prices of pithead coal and new coal contracts are expected to increase up to 10 times (Eberhard , 2008) Discount factors for March of each year are 2005 (126.9), 2006(131.2), 2007 (139.2), and 2008 (153.9) StatsSA

3.7 Key factors affecting the sustainability of inland industrial complexes

Table 7: Key factors affecting sustainability of inland industrial complexes

Factor	Sustainability problem	Technical data	Solutions	Data source
Availability of clean water	Inland complexes are located in dry water sheds that currently are deficit in water demand and import water	For example transfers into the Upper Vaal and Crocodile West-Marico WMAs are required. In 2005 a main source is the LHWP at 670 Mm^3. In 1995, the transfer from Upper Vaal into the Crocodile West-Marico was 875 Mm^3.	Development or increasing efficiency of existing treatment systems	(DWAF , 2002; DWAF , 2004b; DWAF , 2004c; DWAF , 2004d)
	There is no water available for new expansions.	GDP and population growth of demand is c. 2.7% /annum. Additional water from LHWP will be consumed about 2012.	Phase 2 of the LHWP will supply an additional c 21 Mm^3/annum with additional energy consumption for pumping in Lesotho and from the Vaal to the Crocodile West-Marico. Water is transferred from coastal WMAs, ie Inkomati, Usutu and Tugela WMAs (feasibility not established)	(Rand_Water_Board , 2007a)
			Water reuse after treatment. Operating costs are estimated to be between 2-4 $kWhr/m^3$	(Water_Today , 2008)
Carbon cost of water	Pumping of water to mitigate water deficits in 90% of SA's WMAs consumes large amounts of fossil fuel which contributes to global warming	RWB in 2007/8 consumed 10^3 TWhr. and 1M tonnes-CO_2/annum Specific water use of ESKOM is 1.4l/kWhr, and the lowest water use efficiency.	Use of new power stations that use only 10% of the current stations and systems	(Rand_Water_Board , 2007a; Rand_Water_Board , 2007a; Rand_Water_Board , 2007b; ESKOM , 2007a; ESKOM , 2007c)
Build up of salt in inland water system	Salt is toxic for ecosystems and quantities generated are too large for disposal into the surface water system	Quantities not provided in DWAF reports on the inland WMAs or in the SASOL or in the ESKOM sustainability reports. An estimate of highly soluble cation concentrations in coal ash is 1.2%wt (Willis and Crank, 1980). A 3600 MW power station consumes c. 10 Mt/annum of coal, and produces 3 Mt/annum of coal ash which produces c. 36000 t/annum cations. The Grootdraai sub-catchment yields 300 Mm^3 /annum, and the release into the streams would result in additional TDS of 120 mg/l. ESKOM mixes ash with brine to bind salts at 640 t/h at Lethabo (ESKOM , 2007b)	Salt binding in ash OR Dry storage in ash mounds Avoidance is not an option due to the composition of coal.	(ESKOM , 2007b)

Factor	Sustainability problem	Technical data	Solutions	Data source
	Industrial use for brine is believed to be uneconomical due too low quantities, too variable quality and too high processing cost, and an unusable waste for the complex	No data in DWAF, SASOL, and ESKOM reports. Hence the problem has been deduced. Size of problem is to be identified.	"permanent storage" OR New industry	Data required
	Is storage of the salts viable over long timer periods, say 100 years?	Groundwater contamination (need data)	Line storage, deep level injection, transport (need data)	
Waste mine water leads to toxic water pollution	Control of acid mine drainage has high economic costs which go beyond the closure of mines and industrial complexes. (Dates to be established). Intergenerational costs are not sustainable.	60-80 Mm^3 of low pH and high heavy metal concentrations will be released into the Olifants system. This exceeds the natural cleaning potential.	Treat or reuse	(DWAF , 2004b)

3.8 Research questions

Specific research needs have been identified to review and promote best practice in industrial regions (Brent et al., 2008: online material), based on the Kwinana industrial area in Western Australia (Figure 7). The research questions are accordingly based on case study research. The intention of the research is to use focussed MSc Dissertations that address the main research question of the WRC Project, i.e. to assess the key factors that influence the long-term environmental sustainability of an inland industrial complex and the potential synergy for reuse of waste products and opportunities for implementing of integrated technological solutions.

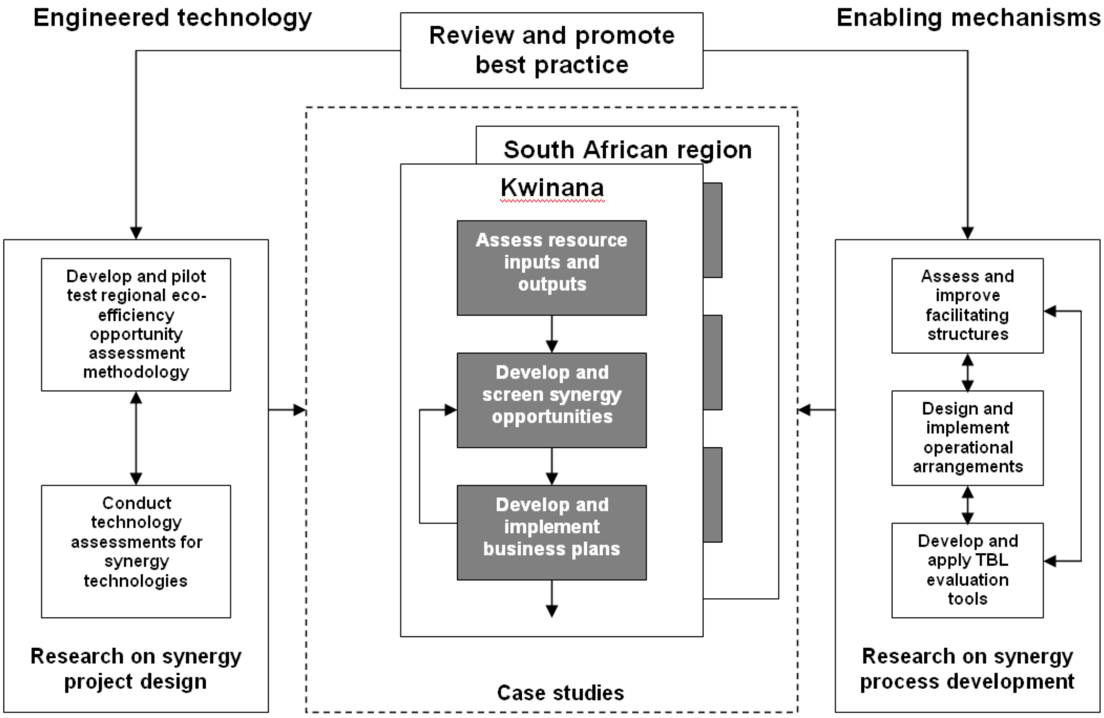

Figure 7: Diagrammatic representation of research question (Bossilkov et al., 2005)

Specific tasks are to

1. compile an inventory of the input, output, and on-site storage of products (including water) within the selected industrial complex(es)
2. evaluate the environmental sustainability of current practices with a primary focus on water use efficiency, and potential to pollute water systems
3. Assess the potential synergy within the complex for reuse of water and waste products between industries and opportunities for integrated technological solutions
4. Identify the regulatory and other stumbling blocks that impede the implementation of synergistic reuse options and integrated technological solutions

Main research questions to be tested are:

1. There is scope for reuse of waste products between industries, i.e. one man's waste is another's raw material.
2. Process integration between members of an industrial complex will result in increased water efficiency in SA inland complexes.
3. Holistic resource management will result in higher carrying capacity for industrial complex ecosystems.
4. A better knowledge base will help identify opportunities whose implementation will ensure sustainability of these complexes.

The sub research questions address the main long-term pollution problems identified in the large industrial complexes, ie, the build up of salts.

1. Assessing technical options using pinch techniques for integrated salt management so as to identify the technical barriers to implementation of cleaner production techniques resulting from waste minimization for water use efficiency, LCA of pollutant impacts from cradle to gate, in the inland industrial/mining complex.
    - Assumptions to be tested
        - Integrated management of salts will increase water use efficiency
        - Integrated management of salts will increase options for beneficiation of salts
        - Integrated management of salts will potentially reduce pollution

2. Assess ecological options other than legal options for waste release into the ecosystem, so as to minimize impacts of the salts. This will be used to identify technological barriers to long term ecological sustainability resulting from the build up of waste residues in the complex's ecosystem.
    - Assumptions to be tested
        - Ecological sustainability can be achieved through integrated pollution control in the complex
        - Legal frameworks can be tested through consultative process with stakeholders, e.g. RQO (Resource Quality Objective) or Desired Future State of riverine systems Protocol (see Section 3.2)

3. Assess technical options for reuse of salts and identify both technical and ecological barriers for the implementation of new technologies to promote sustainability. This is done by use of a new technology and LCA screening of possible impacts.
    - Assumptions to be tested
        - There are technical options for reuse of waste salts

4. Assess the economic, regulatory and institutional barriers to the implementation of technical solutions.
    - Assumptions to be tested
        - There are holistic and non-techno-economic solutions to water use and waste disposal

Sub assumptions that can be tested for the case study (ies):

- Waste mine water can be used as processing water;
- Town wastewater can be used as cooling water;
- Waste processing water can be used in towns;
- Waste processing water can be used in agriculture;
- Salt release can be within the carrying capacity of the inland WMAs; and
- Acid mine water can be treated for reuse.

In addition the CSIR is responsible for coordination of the sub-research projects and integrating the findings for policy.

Primary measures for environmental sustainability for each of the sub-research tasks are

1. Specific water use, technology benchmarks, and ecosystem carrying capacity for water supply;
2. Ecological limits for water levels in the supply catchment, and ecoservice for long-term absorption capacity of pollutants from operations and post closure waste storage;
3. Institutional requirements to ensure technical, economic, and ecological sustainability.

By addressing these research questions it is envisaged that a changing nature of industrialisation in South Africa can eventually be instilled, culminating in a comprehensive industrial ecology approach, whereby all process systems and equipment, with plant and factory design, will eventually be fully compatible with existing industrial ecosystems as a matter of course.

3.9 Selection of complex

3.9.1 Terms of reference: criteria and recommendations for selection of complex

The Terms of Reference for criteria of selection of complexes are based on the requirements for the tasks to be completed. These are:

- Inventory: input output and storage of products and waste
- Environmental sustainability: water use efficiency, pollution of water systems
- Complex cleaner production opportunities: reuse water and reuse waste using integrated technologies
- Barriers pertaining to governance issues and cleaner production opportunities identify and recommend actions for water use efficiency and waste minimization
- Capacity Building

Elaboration of the criteria was achieved using a multi-disciplinary nominal group technique using CSIR specialists in Governance, Pollution and Waste, Cleaner Production. The group consultation used a-two-stage process. This was then followed by discussions with the research partners from UKZN, UCT and the CSIR water Group.

The criteria proposed for the identification of complexes is as follows:

- Information for the completion of the tasks within the required time and resource constraints;
- Accessibility of information to the project team;
- Accessibility to the complex by the project participants;

- Buy in from major industries in the complex;
- Organizational support within the major industries in the complex;
- Dynamics of material usage within the complex, i.e. sufficient to identify opportunities for reuse and cleaner production;
- Clear boundaries (fixed or virtual); and
- One dominant player to facilitate waste reuse and cleaner production within the complex.

In the second stage the list was refined to align with the expressed criteria in the terms of reference, i.e.:

- Inland location, i.e. inland water systems
- Mining, i.e. large-scale mining with large-scale pollution potential
- Industry participation in the complex with the potential for large water consumption
- Virtual complex, in other words, where synergy is best achieved despite geographical distance.

All possible industrial complexes in South Africa were assessed against the criteria defined in Table 11 of the Appendix. A full table with all criteria is contained in a sortable data base which is available on request. The possible complexes for consideration are listed in Table 9.

These complexes are identified from the mining and industrial activities as follows:

- Witbank-Ferrobank (coal mining, processing, stainless steel, power generation)
- Middleburg (coal mining, power generation)
- Secunda (coal mining, gold mining, power generation, synfuel production, and coal/gold ore processing, with agriculture)
- A new complex in the Waterberg coal field (power generation, coal mining, synfuel)
- Steelpoort Burgersfort (PGM and chrome mining and mineral processing, ferro- chrome arc smelting)

These complexes have in common the key factors that influence the sustainability of inland complexes; via:

- Uncertainty of clean water supply in the medium and long term
- Uncertainty of long term stability of waste storage of water soluble salts in slimes dams
- Short and long term build up of salts in the surface water supply for downstream water users
- Uncertainty on energy costs and acceptability of carbon emissions for long term pumping using fossil fuels
- Short and long term acid mine contamination of ground and surface waters.
- Eutrophication of the large dams due to nutrient pollution from water treatment works.
- Increased water treatment costs for water reuse.

3.9.2 Ranking of the five inland complexes

Ranking to get to five inland complexes involved using the following:

- geographical features and water supply and disposal typical of the water sustainability problems for SA inland industrial
- waste disposal sites in complex
- Availability of info to define the problem for research
- Accessibility
- Buy in by industry
- Dynamics of complex (Sufficient to identify opportunities)
- clear boundary
- One dominant industry

Table 8: Shortlist of inland industrial complexes

Industrial complex	**Ferrobank - Witbank (associated with coal mining, stainless steel, power generation, and related industries)**	**Middelburg - Mpumalanga (associated with coal mining, ferrochrome, lime?) - already some aspects of waste exchange in place**	**Rustenburg - (associated with PGM and Chrome mining)**	**Secunda (associated with coal and gold mining and processing, synfuel, agriculture, power generation)**	**New Waterberg (coal mining and processing, power generation, synfuel)**	**Steelpoort/Burgersfort area (associated with Chrome and Platinum Mining, mineral processing, beneficiation, ferrochrome smelting)**
Geographical features and water supply and disposal typical of the water sustainability problems in SA inland industrial complexes	acid mine drainage and heavy metals, pumping of water to complex	acid mine drainage and heavy metals, pumping of water to complex	Mine slime dams and waste disposal due to mining; surface and ground abstraction mainly from mining; agricultural run-off; groundwater contamination from human pollutants due to informal settlements next to mines, Rand Water Board supply is too polluted to used due sewage pollution in Hartebeestepoort Dam,-E.coli, acid mine drainage contaminating groundwater, shortage of clean water, build-up of salts in inland water system	Gold mine wastewater, coal mine open and underground wastewater. High groundwater pollution potential from decanting of closed mines. 2 catchments. Groundwater contamination from slimes dams. Acid mine drainage, pumping of water to complex,	Coal mining, salt build-up, shortage of water, pumping of water to complex	Shortage of water, pumping of water to complex, waste mine water pollution?
waste disposal sites in complex	yes	yes	three garden and four landfill sites operated by the municipality and private contractors; one informal landfill site operated in the tribal area; four private landfill sites operated by the mines; hazardous waste exported by Enviroserve => no hazardous waste 23site	At least two salt slimes dams. Other sites expected.	Yes	Yes
Availability of info to define the research problems	unknown	yes	Yes	in progress	yes	Unknown

Industrial complex	Ferrobank - Witbank (associated with coal mining, stainless steel, power generation, and related industries)	Middelburg - Mpumalanga (associated with coal mining, ferrochrome, lime?) - already some aspects of waste exchange in place	Rustenburg - (associated with PGM and Chrome mining)	Secunda (associated with coal and gold mining and processing, synfuel, agriculture, power generation)	New Waterberg (coal mining and processing, power generation, synfuel)	Steelpoort/Burgersfort area (associated with Chrome and Platinum Mining, mineral processing, beneficiation, ferrochrome smelting)
Accessibility	yes	yes	Yes	Yes	No – still a concept	Unknown
Buy in by industry	unknown	unknown	CSIRO research project already underway	Yes	Yes	Not contacted
Dynamics of complex (Sufficient to identify opportunities)	yes	yes	yes, mine water for process water	yes, mine water for process water		limitations due to direct exchange, ie, mine to farmer; should look at site
Clear boundary	Fairly	yes	yes (upper Hex catchment)	yes	no	no 100 km long
One dominant industry	Steel dominated	no	no, good cooperation on sustainability	no	Yes	likely industry cooperation

3.9.3 Prioritizing of complexes

One intention of case study research is to be able to apply learning from one case study for a number of complexes. The highest prioritization is therefore for the complexes with the most opportunities for learning. The shortlist has Secunda, Waterberg and Steelpoort (see Table 9). Secunda is seen, perhaps unfairly, as being under less pressure for water supply in the short term because of the ready connection to the Rand Water Board pipeline with relatively clean raw water and its strategic classification which gives it first priority for new allocations. For this reason there may be less urgency from the stakeholders, for external research. But the need for a new industrial complex in the Waterberg is high, and as it will in some way be based on Secunda, an outcome focussed from learning on Secunda is judged to be more advantageous than a similarly weighted Steelpoort complex.

Table 9: Shortlist and sum of criteria met on the shortlist of inland industrial complexes

	Final ranking criteria					
Industrial complex	**acid mine water drainage**	**brine (> (5% wt/wt) storage**	**access to data**	**benefits for further complex development**	**limited clean water supply access: incentive for water recycling**	**Ranking: equal weighting for each criterion**
Ferrobank - Witbank (associated with coal mining, stainless steel, power generation, Ferro metal smelting?)	yes	yes	not clear	not clear	uncertain	2
Middelburg - Mpumalanga (associated with coal mining, ferrochrome, lime?) - already some aspects of waste exchange in place	yes	not clear	not clear	yes	uncertain	2
Rustenburg - (associated with PGM and Chrome mining)	yes	not clear	not clear	yes	yes	3
Secunda (associated with coal and gold mining and processing, synfuel, agriculture, power generation)	yes	yes	yes	yes	not clear	4
New Waterberg (coal mining and processing, power generation, synfuel)	not clear	yes	not clear	yes	yes	3
Steelpoort/Burgersfort area (associated with Chrome and Platinum Mining, mineral processing, beneficiation, ferrochrome smelting)	yes	not clear	some	yes	yes	3

3.9.4 Proposal methodology framework

1. The project will gain technical and governance learning from the Secunda complex.
2. The learning will be applied to a governance model of a complex in the Waterberg, which will consist of coal mining, power generation, and synfuels generation from coal.
3. Learning will be shared using a protocol based on the thinking in the DEAT Desired State model for riverine systems.

The identified Stakeholders for the case study on the existing complex are as follow (status of communications with the stakeholders is provided in brackets):

- SASOL Synthetic Fuels Secunda (discussions in progress)
- Sasol Mining mines Mpumalanga Proposed complex
- Evander gold mines Mpumalanga
- ESKOM power generation
- Govan Mbeki Local Municipality (Secunda) (recently completed study on Integrated Pollution Control)
- Agriculture (Waterval, Olifants)
- Pollution and Waste MDALA (recently completed study on Integrated Pollution Control for Mpumalanga)
- WMAs/DWAF (recently completed study on Integrated Pollution Control for Mpumalanga)
- Parks Board (no contact yet)

The stakeholders' interests in water are shown in Table 10. The location of the stakeholders in relation to the water streams and mines, and power stations is provided in Figure 8.

Table 10: Stakeholders interest and commitments measured by water consumption in the case study area (Strauss, 2005; CSIR-NRE, 2000)

Net Water User/ (Producer)	1998 measured Mm^3/annum	2000 expected Mm^3/annum	2005 expected Mm^3/annum	2010 expected Mm^3/annum
Grootdraai Vaal feed				105
Sasol synfuel	63.6	106	112	112
Sasol Mining mines		(5)		?
Eskom power generation	52	57	86.6	92.1
Municipalities Olifants WMA	40.9	47.7	63.6	48.7
Municipalities in the Grootdraai sub catchment				1.8
Municipalities and agriculture in Western Highveld				15

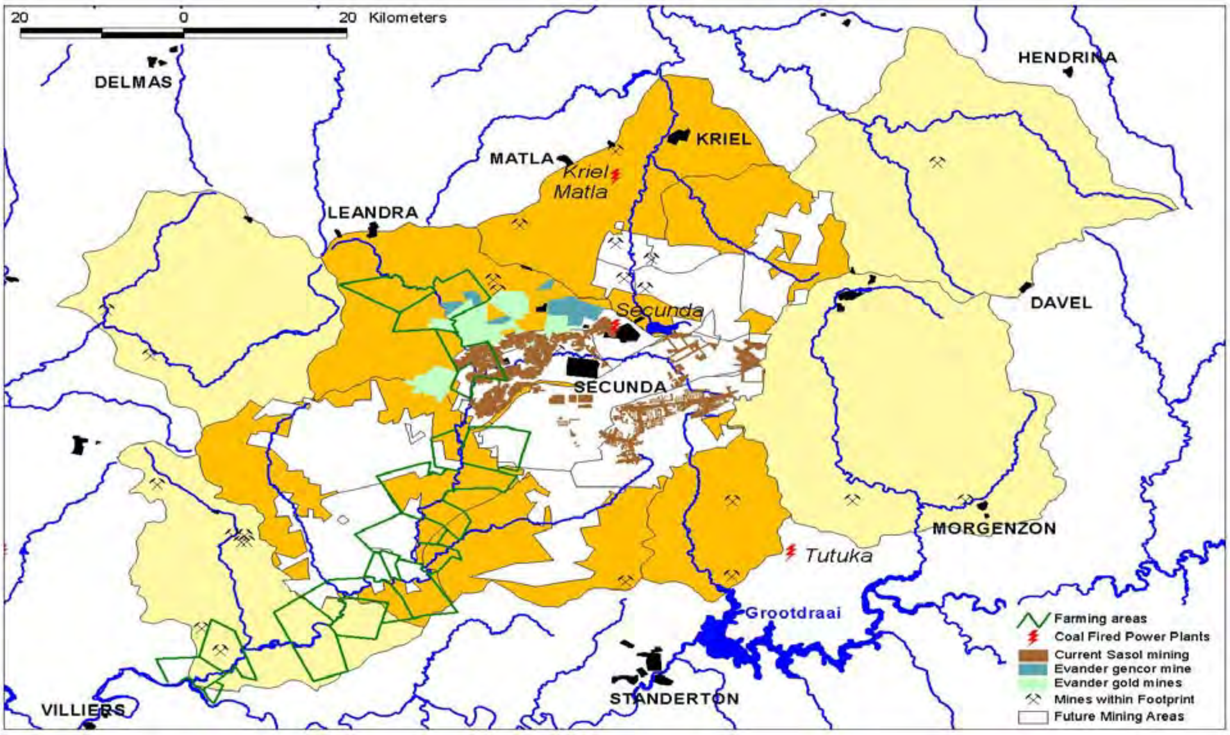

Figure 8: Study area Upper Vaal and Upper Olifants

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Appendix A: Identification of Industrial Complexes

Table 11: Extract from the database with an assessment for the following selection criteria: inland, mining, industry with large water consumption, and proximity

Industrial complex	inland	mining	industry large water consumption	Virtual complex	Comments
Alrode - Alberton Johannesburg	Yes	unknown	No	Unknown	water consumption is not expected to be high enough to justify recycling from the mines
Atlantis - Cape Town	No	No	Unknown	Unknown	
Cato Ridge - KZN	Yes	No	No	Unknown	water consumption is not expected to be so great to justify recycling from the mines
City Deep - Johannesburg	Yes	unknown	No	Unknown	there is no shortage of water in this complex
Coega IDZ - Eastern Cape	No	No	No	Unknown	Currently, the Coega IDZ is not yet populated with industries. An alternative would be the Nelson Mandela Metro, which includes the Uitenhage car manufacturing sector. A fairly detailed assessment of hazardous waste generation in this region was done a few years ago for the Coega Hazardous Waste Facility Siting EIA
Durban South Industrial area	No	No	Yes	Unknown	This is an environmental "hot spot" with strong societal involvement that claims of marked impacts on human health. Information for this complex is readily available but must be subjected to scientific review before application in this project
East London - IDZ - Eastern Cape	No	No	Unknown	Unknown	Automotive sector. Chemical plant may still be operating.
Ferrobank - Witbank (associated with mining)	Yes	Yes	Yes	Unknown	Yet to establish which industries in the complex consumes large quantities of water from the mines
Industria – Johannesburg,	Yes	No	Yes	Unknown	Large number of medium companies, no mining, some metal finishing, automotive sector

Industrial complex	inland	mining	industry large water consumption	Virtual complex	Comments
Isando - Johannesburg	Yes	No	Unknown	Unknown	Automotive sector, some chemical sector. No mining
Johannesburg Airport IDZ - Gauteng	Yes	No	Unknown	Unknown	This is a relatively new complex.
Kimberly	Yes	Yes	No	Unknown	A well publicized problem in Kimberly is the untreated overflow from the domestic sewage works which is diverted into a natural depression – a loss for rare species of flamingos. The problem is associated with domestic water supply. There is no known linkage with industry, and the problem will be resolved as soon as the local municipality brings the sewage works back into operation. There is no large water consumption producing mining sector and no large water consuming industry.
Middelburg - Mpumalanga (associated with mining - Steele, Ferrochrome, Lime factory) - already some aspects of waste exchange in place	Yes	Yes	Yes	Unknown	The complex comprises Middelburg Ferrochrome, Columbus steel and an Agricultural lime manufacturer. There is potential for wastewater exchange and reuse. Currently the lime manufacturer uses the waste from Columbus in their processes and MFC sells a portion of their waste for reuse in construction industry. There is an extreme water shortage in the Olifants river. 167 Mm3 water transferred from Inkomati, Usutu Mhlatuze, and Upper Vaal. Large risk from decanting of coal mines 62 Mm3/annum. Mining, manufacturing and power, 55% of GGP. Ref DWAF. Power generation consumes 219 Mm3/annum. Bulk industrial 20Mm3/annum. Total available is 781 Mm3/annum.
Mossel Bay (associated with gas fields off shore)	No	No	No	Unknown	
Nelspruit	Yes	No	No	Unknown	MMC and Delta mineral processing are not large consumers of water. Nelspruit is a dynamic growth hub at the moment, with increasing development, industry and associated waste generation. There could be information available, since DEA implemented the Waste Information System here, which requires some industries to report. They have also done an IWMP, which should capture information - plus fairly detailed assessment done by CSIR-NRE on integrated

Industrial complex	inland	mining	industry large water consumption	Virtual complex	Comments
					pollution control.
New Castle/Dundee - KZN (Associated with mining)	Yes	Yes	unknown	Unknown	Check power generation, no shortage of water in Usutu Mhlatuze catchment which is transferring water into the Upper Olifants.
Pelindaba	Yes	No	No	Yes	Information is available, but given fact that this is a nuclear site government may be reluctant to share the information for strategic reasons. Also there is a risk of identification of any environmental negligence which is being addressed in separate processes for the Pebble Bed Modular Reactor Project. This is another reason why the waste producers may not want to participate. After a period of reducing activities on site, the renewal in nuclear energy has resulted in new activities.
Port Elizabeth/Uitenhage	No	No	Yes	Yes	Automotive, chemicals, cement, hazardous waste, tanneries.
Richards Bay - KZN	No	No	Yes	Unknown	
Rosslyn - Pretoria	Yes	No	Unknown	Unknown	
Rustenburg - (associated with mining)	Yes	Yes	Yes	Unknown	No water supply problems; forms part of the Crocodile West-Marico catchment with three rivers supplying the complex, ie, Hex-, Elands- and Sterkstroom. Info available from Rustenburg SEA and the SoE: http://www.rustenburg.gov.zapuploads/Environment%20Website/index.htm The industry in Rustenburg is already undertaking an industrial ecology project, so there will be duplication. The quantities of water are not large and there is already reported to be a good water reuse (DWAF , 2002)
Saldanha - Western	No	No	Not sure	Unknown	Some coastal industries make use of large quantities of sea water.

Industrial complex	inland	mining	industry large water consumption	Virtual complex	Comments
Cape					
Sasol Complex - Secunda (associated with mining)	Yes	Gold/Coal, Yes	ESKOM, SASOL, Evander, Secunda, Agriculture, Yes	Yes	This complex water takes water from the Grootdraai catchment (Upper Vaal) about 117 Mm3/annum, and releases wastewater into the Waterval (Upper Vaal) (39 Mm3/annum) and Upper Olifants . Demand is for high quality water for chemical processing, steam energy transfer, and evaporative cooling by the Sasol Synfuel and ESKOM. Wastewater is treated before release into the Waterval/Olifants and is released at flood to reduce concentration. Mine water is taken from fills of open cast coal mines (5 Mm3/annum in 2000). There are at least two depths for groundwater aquifers eg, coal about 30 m and gold mine water > 100m. Both catchments on which the complex is sited have WMA deficits. WRC reports the Upper Olifants deficit at 172 Mm3/annum in 2000, and the Upper Vaal 1310 in 2000 (note latter number does not add up with the Lesotho Highlands data and is to be checked). Closed coal mines will decant between 60 and 80 Mm3/annum. Gold mine water is not considered in the WRC report (DWAF, 2004). Long terms storage of salt brines with no techno-economic solution. Similar complex is being considered for the Waterberg coal fields in the Crocodile West-Marico basin which has a larger water deficit.
Possible new Synfuel/mining and power generation complex in the Waterberg	Yes	Yes	Yes	Unknown	New power stations have dry cooling, so less water is needed for evaporation. Mining will require water for coal washing. It is an Ecologically sensitive area for salt release. See above comment.
Sasolburg, Van der Bijl park, Vereeniging - Vaal triangle	Yes	Yes	Yes	Yes	This complex is seen to be very complex in terms of the wide diversity and the number of small and large industries and the number of industry groups and problems with cooperation, eg, groundwater contamination. Lethabo open cut coal mine for Lethabo power station.
Steelpoort/Burgersfort area (associated with Chrome, Platinum and Vanadium	Yes	Yes	Likely	Yes	New mines for platinum. Two ferro chrome smelters; Samancor's smelter and a Chinese smelter, project Lion will require water for cooling for the off gases. This waste is expected to contain phenols. A new dam is being built and industry may follow.

Industrial complex	inland	mining	industry large water consumption	Virtual complex	Comments
Mining)					Need data on water consumption. The Tubatse business unit, located in the Steelpoort Valley of the Mpumalanga Province, manages both the Eastern Chrome Mines and the Tubatse Ferrochrome smelter. Eastern Chrome Mines comprises of Steelpoort, Montrose, Tweefontem, Jagdlust, Doornbosch, Mooihoek and Groothoek and these are located in the Steelpoort Valley along a 100-kilometre stretch of the eastern rim of the Bushveld Igneous Complex. The total annual production capacity of Eastern Chrome Mines exceeds 2.2 million tons of run-of-mine ore with actual production being dictated by market demand. Run-of-mine ore is further beneficiated to produce grades of ore and concentrates to suit specifications of customers in the chemical, refractory foundry and metallurgical industries. Conventional scraper mining is used. After drilling and blasting ore is scraped mechanically to loading points from where it is transported to shaft tips by locomotives and hoppers. The ore is hoisted to the surface by conveyer belts installed in incline shafts. The sophisticated Tubatse Ferrochrome plant enjoys the economic advantages of being very close to Samancor's Eastern Chrome Mines. Tubatse, an important supplier of top quality ferrochrome, has earned a reputation for supply reliability and efficiency. The five furnaces at Tubatse Ferrochrome are all of the submerged are electric type. A chrome recovery plant recovers metallic ferrochrome from the slag dumps. The area is polluted. STEELPOORT SMELTER The first furnace at ASA Metals' Steelpoort ferrochrome smelter, in Steelpoort, Limpopo, which was commissioned in 1999, enabled the smelter to achieve production of 50 000 t/annum. To increase the smelters' economic scale, ASA Metals embarked on a R144 million project to design, construct and commission a second submerged - arc semi closed furnace at the ferrochrome smelter, with the contract awarded to

Industrial complex	inland	mining	industry large water consumption	Virtual complex	Comments
					Pyromet Technologies in December 2002. The second furnace will increase ferrochrome production to 120 000 t/annum. MARULA PLATINUM Originally designed as a trackless mechanized mine Marula is now part conventional stoping plus some mechanized logistics. With over R2 billion invested in the project this mine is definitely going ahead.
Umbogintwini - KZN	No	No	Unknown	Unknown	The Umbogintwini complex includes a sulphuric acid plant and a paint plant and small industries on the old AECI site.
Welkom - Free State (associated with the Uranium and Gold mines)	Yes	Yes	Unknown	Unknown	Welkom has not been able to attract large industry yet.
West Rand (gold and uranium)	Yes	Yes	No	No	Complex on top of the watershed between the Crocodile West-Marico and upper Vaal and has large dolomitic aquifers. Active mining in these compartments requires dewatering. Pollution of this water includes sulphates, and heavy metals including radioactive metals. There has been research into cleaning water for domestic or industrial use and for removing pollutants prior to release downstream of the Vaal Dam. It is not clear if there are any large potential users for the water apart from municipalities and agriculture. There is no large power generation application and no large processing industry based on coal.