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

Volume V: Linking Technologies to Governance

DEC Rogers, GG Mvuma & AC Brent

WATER RESEARCH COMMISSION

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by

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This report is the fifth 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)**

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EXECUTIVE SUMMARY

BACKGROUND

South Africa's economic prosperity is, to a large extent, associated with a few large industrial complexes that are located close to inland mining areas that are water stressed. Since they are the centres of economic growth, there is a national need to ensure that they continue developing wealth in a sustainable way. This requires security of supply of primary energy and raw minerals, as well as water for processing. In the energy sector two thirds of the energy is lost due to the inherent conversion efficiencies for the coal to electricity and coal to liquid fuel technologies. Most of this lost energy is removed by evaporation of clean water. However the availability of clean water is near the sustainability limit of the current water supply system and the strategic intention has been to reduce demand on clean water by improved industrial water use efficiency, and supported by recycling waste mine water. Salinity of mine water in the case study area is in the range 3000 to 7000 mg/l, so increased mine water usage requires additional inland salt storage capacities.

In the mining sector resources are not renewable and growth is therefore a cycle over the life of the mine. In the processing industries alternative mines can be sourced, and therefore the processing industry has the option of life cycles of several mines. Processing industries are large consumers of water and as water is a renewable resource, the life of the processing industry is limited by the continued availability of clean water. As the limits to availability of clean water are now being reached economic growth based on increasing quantities of water is not sustainable. Research on Cleaner Production techniques is being directed to the mining and processing industries to increase efficiency of water use with the long term objective of avoiding these limits to growth.

RATIONALE

This research project addresses the governmental and technological constraints to application of Cleaner Production techniques. The main constraint addressed here is the environmental sustainability of the current practices of using saline water in place of clean water, with a focus on the sustainability of the waste salt storage problem.

The brief of the project is to assess the potential for integrated Cleaner Production technologies, i.e. where a complex view on water conservation can provide opportunities for more efficient specific water use, and less waste. This integrated Cleaner Production approach is related to the two research areas; integrated Eco-efficiency, and integrated Industrial Ecology.

This volume of the research integrates the findings of the technological and water systems studies in Volumes II and III, with the findings of the social perceptions and governance processes in Volume IV.

OBJECTIVES AND AIMS

AIM 1

Consolidate the two sets of findings from the Governance study and the Technology studies into one set of findings.

AIM 2

Develop one set of recommendations for the development of integrated Cleaner Production case studies with the industries and stakeholders in the complex.

SUMMARY

The main finding for this study is that the long term increasing trend for unaccounted salt flows to the surface water systems indicates control of salt storage and disposal is the key factor for environmental sustainability. The economics of desalination and waste storage are driven by the cost of water and the management of post closure liabilities. These two parameters are controlled in the governance system for clean water conservation, and mine water production which is the main source of salts. A key weakness in the governance component appears to be the absence of public data on relative techno economic and environmental performance data for alternatives identified by stakeholders in the complex. Research is currently system specific, proprietary and therefore uncoordinated. Findings on capacities and leakage are not reported in the public domain. Reasons are understandable given the liabilities that are involved, but the threat of long term pollution is a public concern and the responsibility for ensuring a long term working system falls under the NWA and Department of Finance.

Integrated solutions are not possible unless the technical problem is defined from an integrated analysis of the chemical processes and flows through the different industries in the complex. There are two options to identify for integrated projects; integrated Cleaner Production and integrated Eco-efficiency projects. A discussion on the differences between these is provided in the Inventory report (Volume II). Eco efficiency includes aspects of economic sustainability and is preferred to Cleaner Production.

The issue of building trust has also been highlighted by the eMalahleni Water Recovery Works project in the presentation “Building Relationships of Trust-what we have learnt from eMalahleni that will guide us into the future” (Günther, 2011). The EWRP learning is that the “key to successful engagement is early and sustained consultation”. If that learning is correct, then what is needed now is an economically viable technology and business plan.

Recommendations for further research

Learning from this project indicates that the problems of technology selection and economic viability are less complex when there are

- A sustainable economic plan to eliminate uncertainty on post closure liabilities, and
- A set of technologies that can be made to work using a purchase contract for the recovered water.

Factors that were missing from the current set of plans are the

- Boundary setting at the border of the NWA Section 21 facilities, and
- Paying clients

Therefore research, or at least application of the findings of this project, should be directed to the testing of technical solutions and economic plans based on boundaries identified by an Environmental Impact Life Cycle, a liability quantification, and a life cycle costing. This research may require a change to the boundary of the proposed complex. For example, a greater emphasis can be placed on the participation of the Govan Mbeki LM which is already faced with water charges that are close to those of a water reclamation plant.

The main environmental uncertainty appears to be around the long term stability of the salt storage systems. The systems were established under a different regulatory framework which had a much lower concern for water shortages, long term salination and decanting of acid mine water. Definitive guidelines on salt storage and post closure management of the salt stockpiles have not been developed and subjected to scrutiny of public review. This appears to be a key barrier to the quantification of environmental and economic sustainability.

The key sustainability problem is how to reverse the trends of positive feedback on the salt storage problem. Another concern is the increasing trend in salination and risk of AMD pH dependent river flows. Research tasks to clarify these issues are provided in Section 7 “Recommendations for implementation of the findings and further research”.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

a	annum=year
AOL	Anglo Operations Limited
BFW	boiler feed water
BWPCW	Brugspruit Water Pollution Control Works
CDS	Controlled Discharge Scheme
CPI	Consumer Price Index
CSIR	Council for Scientific and Industrial Research
d	day
DWA	Department of Water Affairs
EC	Evaporator Crystalliser desalination
EWRP	eMalahleni Water Reclamation Plant
FW	Fissure Water
Incl.	including
kl	kilo litre
LHWP	Lesotho Highlands Water Project
LM	Local Municipality
l/uso	litres of water consumed per Unit kWh Sent Out
m	Meter
MFA	Mass Flow Analysis
mg/l	milligrams per litre
Ml/d	mega litres per day water flow
MPRDA	Mineral and Petroleum Resources Development Act, 2002.
Mpu	Mpumalanga Provincial Government
MW	Mine Water
N.A.	Not Applicable
NEMA	National Environmental Management Act 1998
NEM-WA	National Environmental Management-Waste Act 2008
NWA	National Water Act 1998
R	Rand
RO	Reverse Osmosis
RQS	Resource Quality Services-DWA
RW	raw water
SM	Sasol Mining
SS	Sasol Synfuels
t/d	tonnes per day mass flow
TDS	Total Dissolved Solids in South Africa
TDS.	Total Dissolved Solids outside South Africa
TWh	One million kWh
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
WA	Water Act 1956
WRC	Water Research Council
WW	Industrial Waste Water
WWTW	Waste Water Treatment Works, municipal sewage works

1 INTRODUCTION AND OBJECTIVES

1.1 Integration of key findings from the preceding studies

The overall objective of this WRC study was to assess and determine the key factors for the environmental sustainability of a large inland industrial complex associated with mining. The Highveld Coal Field Mining and Processing Industries Complex is used as a case study. The other components of the studies comprised of:

- The Inception report (Volume I) which describes the national problem and the selection process
- The Inventory report (Volume II) which comprises a set of stakeholder-specific inventories for each of the main salt and water processes so as to identify the sources and destinations of the salt and water flows;
- An Environmental Life Cycle assessment (Volume II) of integrated Cleaner Production interventions
- A Governance assessment (Volume IV) based on a survey questionnaire and interviews of critical stakeholders so as to identify perceptions and prioritize recommendations on how to improve the environmental sustainability of the complex.

Findings have been consolidated into four final reports which are summarised below in section 3.

2 APPROACH

The approach is to synthesize an integrated understanding of the perceptions as regards improvement in governance and improvements in the way that technologies can be applied. The focus is on governance instruments and private sectors ownership of the businesses based on the technologies made economically viable by the Governance instruments.

3 PREVIOUS STUDIES IN THE WRC PROJECT K5/1833/3

3.1 Volume I Inception study

In Volume I a review of the national water quality and supply problem identified higher than expected demand for clean water. Reasons include higher growth in the economy, and in the urban areas. There was also the unexpected increase in untreated waste from municipal sewage works and saline mine water discharges.

An expert group identified the characteristics of complex that would enable research to be carried out within the planned three year time frame for the project, and that would allow the most learning and provide most options for implementation of the research findings. This mining and industrial complex located above the Highveld coal field and the eastern edge of the Witwatersrand gold field was selected from a short list of 6 complexes. Major industries include gold mining (Harmony Evander Gold), coal mining (Sasol Mining and AngloCoal New Denmark Colliery), electricity production (Eskom Tutuka and Sasol Synfuels), and liquid fuels, explosives and polymer production (Sasol Synfuels). Part of the complex is located in the Govan Mbeki local municipality which had been the subject of an integrated pollution control and waste management governance research study between 2005 and 2008.

3.2 Volume II Inventory study

In Volume II a mass flow analysis identified the sources and estimation of water and salt in each industry in the complex. A comparison of the mass flow through the surface water system in the complex and the industry discharged identified possible leakages from salt storage areas (including underground water). This comparison provided a quantification of the long term trend of salination in the surface water system due to the mining and industrial salt wastage.

A life cycle analysis of the natural and industrial processes that produce the salts located the main source of salts.

The main source of aqueous salt is reactions between low salinity fissure water 250 to 850mg/l fissure water flows down fractures in the rocks mainly during the rainy season, and the reacts with reduced sulphide minerals and basic minerals in the coal and gold seams underground. The result is mine water with a salinity between 1000 and 7000 mg/l. The salinity increase is lowest for working areas where the residence time underground is shortest due to continuous pumping. The transfers of mine water to the surface operations have been estimated at around 382 t/d. Most of this salt ends up in the aqueous salt storage systems above ground. A second source of aqueous salts is water treatment chemicals at 155 t/d. The third contribution to aqueous salts is coal ash but has not been quantified. An upper limit of 2647 t/d has been calculated for the water soluble components in coal ash. These salts are considered by the industry to be immobile because they are not put into contact with clean water, and therefore are kept above their solubility limits due to very saline concentrations in the ash beds. The transfer from ash beds to the aqueous salt system is being researched by Eskom and Sasol.

The assessment concludes that the capacities of the ash storage systems are exceeded. The cause is the governance policy of replacing raw water with mine water. For this reason the strategy of replacing raw water with mine water should be reviewed and other cleaner production options should be considered.

It is recommended to use integrated Eco-efficiency projects in place of integrated Cleaner Production projects, because the former requires economic sustainability as a condition for commencement of the project.

3.3 Volume III Life cycle study for integrated cleaner production options

Volume III provides a review of the Cleaner Production pilot projects in the processing industries. These projects include recovery of saleable salts such as soda ash (Na_2CO_3) and $CaCO_3$. Production has prioritized desalination technologies for production of boiler feed water and cooling water. The main technologies are Ion Exchange and Reverse Osmosis. A comparison of the integrated environmental impacts of these two technologies was carried out using the CML 2 baseline 2000 impact factor data base. Global Warming Potential, rain water acidification, surface water eutrophication, human toxicity, freshwater aquatic toxicity, and abiotic depletion impacts were compared for the two technology options. The impacts with the decisive differentiation of the two desalination options were the aquatic toxicity of the aluminium sulphate for Ion Exchange, and the abiotic depletion and global warming potential for coal fired electrical power to the Reverse Osmosis unit. The net finding is that Reverse Osmosis has the highest environmental efficiency. The industrial preference for Ion Exchange desalination is based on cost for boiler feed water production. The issue of cost for water, waste water and salt disposal, were not included in the environmental life cycle comparison.

3.4 Volume IV Assessment of the governance systems

In Volume IV a survey of the perceptions of the stakeholders identified two key factors. These are: equitable application of regulatory and economic incentives; and preservation of the economic productive capacity of the water supply and waste disposal systems. Consensus is that the price of water was too low to enable economically viable water recycling. There are expectations that the Minerals and Petroleum Resources Development Act (2002) will provide options for transfer of liabilities to the state for any possible surface water salination post closure of the mines. However the National Water Act with the National Environmental Act relies on principles of Polluter Pays and Cradle to Grave ownership of waste. Possibilities for residual liabilities in the mining and processing industries are seen as a deterrent to unsustainable waste storage practice. These differences in perception indicate that a clear line of responsibility is not present in the regulatory and monetary policies for sustainable water systems over the life of the complex. The main recommendations from this study are: coordinated planning and control for storage; discharge of waste from the complex; and Economic incentives and public infrastructure investment to make water conservation projects economically viable.

3.5 Measurements of sustainability

The principle of sustainability that has been agreed by the research team is the matching of the systems of supply and demand for environmental services over a longer term. This matching of supply and demand is fundamental to the concept of eco-systems. The concept of environmental services is commonly used for eco-systems, and in the case of industry and the environment, can be extended to include the supply of clean water, and the cleaning capacity of the surface and ground water systems for salts that are disposed into the system. Therefore sustainability can be measured by water quality and quantity, and demand for discharge of salts from the complex. A long term increasing trend in surface water salination is not environmentally sustainable.

Economic sustainability for environmental services is governed by the economic law of supply and demand. This is controlled by incentives and penalties, which adjust demand for eco-services (Rogers & Banoo, 2005; Rogers et al., 2005). A good example of the combination of an economic and biophysical model to establish sustainable demand and supply of an environmental service is the Stern Review (Stern, 2005) for carbon emission induced climate change. The highest carrying capacity with the lowest economic cost has been empirically established using insurance company claim records. Over the past 100 years the frequency and size of damage claims resulting from large cyclones correlated with the change in CO_2 and ocean surface temperatures. The Stern Review concluded that the economic cost of exceeding the carrying capacity for CO_2 absorption is more expensive than the cost of not exceeding the carrying capacity. Conventional economics provides a limit to how far ahead investments can be made to manage supply and demand for environmental services (Stern, 2005). This indicates a time limit to the usefulness of conventional economics for establishing environmental sustainability based on supply and demand for the industrial complex.

The Governance survey indicated that most of the technical personnel involved in day-to-day management of water treatment and water supply and disposal perceived the economic valuation of water by DWA as one of the key factors affecting the sustainability of the water supplies. An indication of the perceptions on water prices provided during interviews with the industries and the DWA is compiled with published data in Table 1.

Table 1: Indications of comparative charges and costs for water excluding VAT

Water quality	Application	Charging system	Indicative charges /m^3	Disposal charge for waste water /m3	Total Cost /m3	Citation
Unpolluted stream, surface and bore hole water	Domestic, forestry and irrigation	DWA to farmers	R 0.00 to R 0.04	N.A.	R 0.00 to R 0.04	(DWA, 2010)
Raw water	Power Generation new power stations, e.g. Cooling Water	DWA and Rand Water Board to Eskom	Up to R 2.38 in 2007	Not known	Up to R 20 in 2010	(Wolfaardt, 2007) (ESKOM, 2010)
Piped, Potable Water	Municipal and industrial use	Rand Water Board to municipality	R 3.60	R 0	R 3.60	(Rand_Water_Board, 2007)
Piped Potable Water	Domestic, commercial and industrial, incl. disposal	Municipality to house owner	R 7.25	R 3.96	R 11.21	(Tshwane Metro, 2010)
Mine water	Industrial cooling, and steam system	In house costing system	Up to R 20	Not known	Not known	(Sasol Synfuels Secunda, 2010)
Acid mine water pH < 3 and TDS > 3000 mg/l	EWRP desalination to Potable Water	20 year contract with Emalahleni LM	From R3.90 with CPI adjustments from 2007	included	R 3.90	Anglo Operations Limited (Günther, 2011)

Of interest to an investor in an Eco-efficiency project is the very low charge to agriculture for abstraction of raw water, compared to provision of Potable Water at pressure at a domestic household or industry. Also of interest is the similarity in pricing for RWB supply to Johannesburg and for reclamation of Potable Water from Acid Mine Drainage. (Note: Not available are the discount rates for the investments in processing and treatment plant).

3.6 Time scales observed in the case study area

It is known that social planning systems and biophysical control systems determine options response times to changes in the case study area. Four factors that affect the time availability of water for the sustainability of the complex are proposed in Table 2.

Table 2: Typical operating cycles that indicate the types of response times expected for causal loops in the water system

Factor	Observed impacts	Operating cycle	Observed Mitigation actions
Natural precipitation cycles	Wet and dry periods can change annual average stream flows by a factor of two (Volume. II)	10 years +	National water management system where water from one area is transferred to another, and dams storage is matched to 5 year consumption cycles
Population growth	1.1% p.a. average for Stats SA 2001 to 2008 (Stats SA, 2008)national population; and 6.3% p.a. for Govan Mbeki mainly 2001 to 2006 urban areas (CSIR-NRE, 2008b)	Up to 100 years	Coordinated planning of urban infrastructure for water supply with 3 year planning cycles for investments in long term urban planning
Sustainable Development policy	Expectations from underserviced communities for increased supply of domestic Potable Water, and sanitation reticulation. 100 000 households in Govan Mbeki with 41% of the population not reaching minimum standards (CSIR NRE, 2008)	Millennium Development Goal 15 years	Reduce demand in industry water supply by 5-10% to existing processing industries. Transfer demand to underserviced municipalities.
Investments in additional water supplies are required	The first feasibility study on the Lesotho Highlands Water Project was in 1983. The construction was completed in 2002, in 2008, and the dams are expected to be filled to full capacity around 2012.	20 to 30 years	The next phase of the LHWP has been approved in principle

The life of the infrastructure investments of each component of the complex has been provided by the stakeholders during the interviews. These are summarized in Table 3. The stakeholder with the shortest production horizon is the gold mine. This is due to the threatened closure as the result of the increase in the Eskom tariffs. (Demand is 42 TWh/m). The remaining mining and processing industry planning horizons are about 30 years. The longest term planning horizon is for the agricultural industry, which is also the oldest. Planning of time scales of four generations are considered feasible for family businesses.

Table 3: Perceptions of stakeholder planning horizons for economic production from resources in the inland industrial complex

Stakeholder	Current planning horizon and (commencement date)	Resource factors that are considered a threat to production over the planning horizon
Sasol Synfuels	2040 (1982)	Factors that affect the planned life include the availability of planned life of the coal mines, and extensions or changes from coal to gas as a raw material
Sasol Mining	2040 (1982)	Extension of mining for export coal market; continuation of production from coal beyond 2040. Possibilities for underground carbon sequestration and expected to be for the study area, but may be possible at other locations.
Harmony Gold	2010 (1958)	Depends upon the gold price and the electricity price
ESKOM Tutuka	2040 (1982)	With a refurbishment in 2020, the power station may still operate for up to 60 years from date of construction (1980). Quality and quantity of coal from New Denmark is limiting production and increasing cost of electricity compared to other power stations with larger and cheaper coal supplies.
AngloCoal New Denmark	- (1982)	Depends upon the economic Life-of-Mine; yields of 4.5 Mt/a are less than half of the 11 Mt/a production that the mine was planned for, but coal prices are following the increasing oil price, and yields may increase with higher selling prices.
Local Municipality	2014 (after 1998)	Access to resources for a competitive Industrial economy after gold and coal mines and SSF plant closures are not yet proven. 40% of the population is employed. The industries in the complex are main employers. Agricultural industry employment is dependent upon clean water for irrigation. Water efficiency and unaccounted flows in distribution systems.
Irrigation and animal farming	~2100 (~1900)	Long term trends in salinisation of surface water flows, untreated sewage from Municipality, and possibility of long term trends of falling pH in catchments. Dependency on piped potable water supply from industry to the farms. Reduction in stream flows 6 Ml/d of water released into the Waterval system by industry, and 22 Ml/d by the urban complex.

4 EXTRACTION OF THE MAIN FACTORS IDENTIFIED IN THE SPECIALIST STUDIES

4.1 Governance key factors

The framework adopted to describe governance in water services in terms of policies and legal management, institutional arrangements, administrative and economic issues, financial management, technical compliance, and levels of participation, is described in Volume IV. It is based on previous work at the CSIR on Governance. The CSIR study on Mpumalanga Integrated Pollution Control (CSIR-NRE, 2008a) was based on the United Kingdom Department for Foreign Investment and Development (Plummer&Slaymaker, 2007). Table 4 provides a summary of governance related issues.

Table 4: Summary of key issues from a governance perspective

Issue	Impact/perception/consequence	Comments
Current water demand exceeds forecast	Perception of all: raw water is abundant for the strategic industries in the study areas. Consequence: Water scarcity is experienced before the forecast time.	The forecast water demand estimates for Highveld Mining and Processing Industries Complex area was 259 Mm^3/a and 277 Mm^3/a in 2010 and 2020 respectively (Volume I), but the study has shown that this has already been exceeded, namely currently at 335 Mm^3/a in 2008/9
Price of water is low	Perception of industry: The price of raw water is so low, that it is cheaper for industry to waste water than to attempt to reduce consumption, and recycle and treat it. Perception of industry: The level of levies is not an economic incentive for industry to change the way they use water. Perception of government: Raising the price of water will raise the cost of living.	This implies the possibility of fixing the price of water to a demand supply ratio, but opinions in the public sector differed as to the effectiveness.
Inequitable in application of water quality standards	Perception of industry: Lack of exercising more equity on the application of water quality standards across the board. Perception of industry: Currently the mines have a lee-way in not treating the mine water before transferring it to other industries for use as raw water. Consequence: In practice, the reuse of streams occurs seldom because of the variety in (mine) water quality with respect to the available plants. Impact: The variation of mine water quality directly affects treatment costs.	With deterioration of water feed, industries use more chemicals to treat the water and in the end produce more saline (salts) effluents. The impact in the increase of salinity in the ash water system is a large concern for industry. An important governance factor that emerged from the study is that there is a lack of enforcement of the water quality standards on the part of government, which contributes to liability (see issue below).
Liability for stored salts/wastes	Perception of industry: Under the current waste management regulations storage on site is permitted if there is a potential resource. Alternatively the waste should be disposed within the carrying capacity of nature. Impact: Process waste covers around five squared kilometre of ash and slime dams and product waste has the order of magnitude of thousand million tonnes	From a governance perspective this transfers the waste problem from one medium to another, or delays the implementation of safe waste disposal practices. Who is responsible for the environmental loads from waste disposal and storage after site closure becomes an important governance issue.
Who is responsible for Liabilities	Perception of all: Liabilities arise from the duties of care that are expressly provided for in NEMA, NWA and NEM: WA, MPRDA, and others.	Another aspect is the process of licensing which does not clearly spell-out the transfer of liability after the closure of the plant. For example, it is believed that liability for waste mine water might increase if two mine water wastes are mixed. That is if the waste is transferred from one DWA permit to another. Liability options for waste reuse are not clearly outlined at present. This problem is exacerbated by the slow implementation of permits under the NWA. For business of water recycling some, this is clearly a hindrance for the concept of integrated project development.

4.2 Surface water flows key factors

The main findings of the surface water study are summarized in Table 5.

Table 5: Summary of key factors from surface water study

Factor	Impact/perception/consequence	Examples
TDS flows in the Waterval at the boundary of the complex are within Permit and surface stream water guidelines	Perception: salt storage management in the catchment area is under control of the Permit system.	See statistical analysis for C1H8 water quality and flow calculations in the Inventory report.
TDS levels over the last 10 years in the Grootdraai dam are close to pre-industrial levels	Consequence: the current rate of pollution from the complex into the Grootdraai Dam, and the rate of abstraction are sustainable in the context of desalination by Eskom and Sasol Synfuels.	See DWA Statistical analysis of Grootdraai water quality in the project files.
Current Surface Water TDS flows (t/a) are greater than background and permitted release rates in Leeuspruit	Perception: Additional sources of TDS are present in the drainage area. Perception: Additional sources are most likely associated with either diffuse leakage from contaminated Ground Water, or unpermitted point discharges.	There is a history of long-wall mining in the area which is associated with extensive fracturing of the rock overlaying the coal seam for up to 1.5 km from the compartment (Hodgson&Krantz, 1998).
Surface TDS flows have increased dramatically since onset of mining in the Leeuspruit	Perception: Rates of release of mine water to Surface Waters are increasing size of underground compartments.	Leeuspruit catchment (Volume II)
Surface TDS flows over 30 years have increased in the Waterval without a clear trend	Perception: Multiple trends may be present in the data as the result of several industries; each with initiation dates ranging between 1958 and 1982; and with mitigation and expansion programmes, as well as possible failures of salt storage systems	Waterval catchment: C1H8 salt loads appear to have dropped in the period 1999 to 2008. This indicates the possibility a drop in industrial discharge. See (Volume II).
Mines indicate an initial increase in pH. Data indicates a reducing pH. Rising TDS is seen in the surface water flows.	Perception: This falling pH and increasing TDS may be an early indicator of mine water acidification in flooded compartments	Leeuspruit for 33 years of monitoring data at C1H5 and Waterval for 35 years of monitoring data at C1H8. (Note: This data is to be verified with DWA.)

4.3 Salt storage key factors

The main findings and key factors affecting the salt storage system, from the inventory report, are as follows:

- Salt storage capacity is an issue as loads since the introduction of mine water desalination regulation, might exceed long term storage capacity. Additional storage capacity is being sought. Storage capacities and long term stabilities are still being researched and public guidelines are not available. Agreements on safety of storage are still being developed.
- In the Waterval catchment any leakage from salt storage is less than 18 t/d. In the Leeuspruit catchment leakage from salt storage may be as large as 20 t/d. The salt flow leaving the mine water is 382 t/d, and about order of magnitude less than salt minerals in ash. Results of previous studies indicate that the issue of mobilization of these salts has not been resolved.
- As salts are used to desalinate mine water and saline waste stored on site, there is an additional load of around 155 t/d of treatment chemicals. Technology options to reduce this salt loading are discussed in Volume III and Volume IV.
- It is now clear that the DWA water saving policy in a zero discharge regulatory environment increases the inventory. This leads to a trade-off between short term and long term needs. In the short term there are clearly understood savings for the additional access to limited supplies of clean water, and clearly understood costs for commercial industry. In the long term there are poorly understood risks for timing and long term economic costs to economic profitability for commercial stakeholders.

An analysis of the consequences of these findings is provided in Table 6.

Table 6: Summary of key factors from salt storage study

Factor	Impact/perception/consequence	Examples
Current salt and water loads from mine water are greater than storage capacity of ash and underground storage	Consequence: Other forms of salt storage/disposal are now required Perception: It is not clear how the large discharge rate during operations will halt at the time of closure Perception: It is not clear how large quantities of underground mine water can be isolated from the Ground Water and Surface Water systems without continuous pumping. Consequence: Additional capacity in surface storage systems is required.	ESKOM Tutuka ash disposal site; Sasol Synfuels Ash Water storage and disposal system Mines discharge on average 68 Ml/d in the complex. Unaccounted for salination of surface water systems is observed
Current salt storage underground has significant inflows rates to un-flooded compartments	Perception: There is a risk for salt storage leakage flow to the ground water system; and there to surface water flows Perception: Therefore salt leakage from flooded compartments cannot be controlled Consequence: Further data on underground salt storage is required in the complex before planning on costs and controls for long term leakage and post mine closure.	AngloCoal New Denmark
Knowledge of how to optimize, and control long term storage of salts in the complex is ash dumps has not been published in the public domain.	Perception: It is not possible at this stage to accurately predict costs for control of leakage of salts from ash dumps. Consequence: Either further research is required before long term planning for storage technology and provisions for costs are finalized, or provisions for long term monitoring and management of salt leakage should be published in WRC guidelines	Sasol Synfuels and ESKOM Tutuka for ash paste systems Sasol Synfuels, ESKOM Tutuka

4.4 Integrated technical solutions key factors

The current status of technologies assessed to date has been evaluated, and two approaches have been prioritized. These two approaches have been assessed using high level life cycle evaluation in Volume III. The findings on the key factors are summarized in Table 7.

Recommendations for integrated technical approaches are to be assessed using criteria based on a total environmental impact assessment for functional units based on a

- 1 Ml/d Reverse Osmosis energy recovery plant, compared to the existing Ion Exchange plant, and a
- 1 t/d Na_2CO_3 plant, compared to the existing supply from Botswana Soda Ash.

Table 7: Summary of key factors from technology integration study

Factor	Impact/perception/consequence	Examples
Rate of salts accumulation has increased as the result of large scale use of ion exchange desalination	Replacement of Ion Exchange by Reverse Osmosis will reduce salt generation rate 4 to 5 times for the boiler feed water system.	Boiler Feed Water system at Sasol Synfuels.
Commercial salt recovery has yet to be proven practicable	Perception: It is not possible viable to recover salts on a large enough scale to reduce the salt inventory Impact: Alternative technologies such as eutectic freeze crystallisation are of interest in the South African context WRC Project K5/1669/3 2008 (Proxa, 2009)	Production of $CaCO_3$ and Na_2CO_3 using CO_2 from the evaporator crystalliser

4.5 Integration of key factors from specialist studies

A selection of key factors has been prepared. This is not exhaustive and not prioritized. Two approaches could be followed. One approach is to expand the consequences resulting from each factor by building evidence for the importance of the factor. Another approach could look for new key factors that are the consequence of two or more causal factors. This analysis is beyond the scope of this project. It is proposed that such an analysis be considered for future work; for example, as part of an extension to the stakeholder consultation. In the meantime the following integration is provided.

Table 8: Integration of factors identified in each study

Factor	Impact/perception/consequence	Examples
Increasing inventories of salts indicates a positive feedback system on salt management (Inventory, Governance and Technology studies)	Consequence: Current technical approaches to the management of the salts are not working Perception: New integrated Eco-efficiency projects are required Perception: Economic incentives and changes to resource controls are required to ensure long term security of supply.-	Sasol complex Eskom/AngloCoal complex
Current surface TDS flows are greater than background and permitted release rates (Inventory and Integration report)	Perception: The permit system can result in uncontrolled release from diffuse sources Perception: The permit system allows surface water pollution levels approximately 10 times higher than baseline levels. Perception: the permit system may not be able to restrain diffuse pollution to surface water norms over the longer term Perception: The onset of uncontrollable acidification of mine water may have commenced	Surface Water Study: Leeuspruit below the complex where the limits for point release of TDS is 105 mg/l, and where base line TDS was 205 mg/l now have an average of 240 mg/l and peak values as high as 3500 mg/l Water quality guideline is 2000 mg/l If ground water leakage to the surface water system is the cause of increased TDS, then long term pumping should be provided. This becomes problematic when mines are no longer economically viable (Hodgson&Krantz, 1998) Long term pH trends indicate change in pH with mining activities. pH initially increases and then declines. Observation during the Inventory study.
The water use permit system has objectives that differ from the water quality management system	Perception: The replacement of raw water with mine water is intended to make more raw water available for new social and industrial development in other regions. Perception: The policy of using mine water may be overloading the salt storage capacities and reducing water quality unsustainably.	Tutuka accepts 73 t/d of salt from the AngloCoal mine. The mine accepts 10 t/d of brine back from Tutuka. The ash dump cannot accept any more salt.
Use of mine water in place of raw water is not environmentally and economically sustainable for current salt storage technologies. (Governance and Inventory studies)	Consequence: an alternative cost system should be evaluated. For example, transport the waste salt to the sea to reduce the inland salt impact risk.	

Factor	Impact/perception/consequence	Examples
The stabilities of salt storage technologies are still being researched in order to establish capacities and leakage profiles (Inventory study)	Consequence: the risk of liabilities associated with leakage from long term storage in ash dumps and underground compartments are uncertain. (Governance study)	A literature and stakeholder survey has not revealed places where this information can be obtained (Inventory study)
Most of the salts being generated are in the ash. Water soluble mineral salts. (Inventory study)	Consequence: the magnitude of the soluble salt storage inventory is higher than has been previously reported. Impact: the combination of a low knowledge base amongst the stakeholder on the stabilities of ash salt storage, with a larger salt quantity indicates a higher need for further research on long term salt storage.	Sasol Synfuels and Eskom disposal sites
Institutional alternatives to desalination of mine water will reduce salt impacts (Governance study, and Inventory study)	Perception: Low salt water could be used for power generation to replace high salt mine water. Perception: Reduction of unaccounted for water losses in the urban areas might reduce the need for salt storage.	Unaccounted water loss in Lekwa municipality is 30% of the municipal allocation. If this was water loss was about 10 Ml/d, the salt loading problem would be reduced by 50 t/d of mine water salts and about 25 t/d of chemicals.

5 THE THREE MAIN THEMES OF SUSTAINABILITY

Based on the specialist studies and the stakeholder survey, the authors have proposed the following main themes for sustainability which provide positive feedback loops in the social and technical systems

5.1 Water demand exceeds capacity

South Africa has an advanced water supply system which enables economic development in dry areas. The system has been integrated so that water is transferred to the location where economic development is to take place. A shortfall in one area translates to a short fall in the whole of the water supply system.

In the problem definition component of this research project it was found that the demand for water will exceed supply in 2012 as the result of population and economic development (Volume I). The infrastructure for supply has not been significantly increased since completion of Phase One of the Lesotho Highland Water Project around

2002. The Second Phase has been fast tracked since the problem definition(Ashton, 2010).

UNEP has classified South Africa as a water scarce study. The scarcity is not for polluted water, but for clean water. This is part of a Global phenomenon. It is exacerbated by SA sewage treatment systems and increasing quantities of underground mine water. The philosophy behind water return rather than evaporation is that the water recourse is conserved via recycling. The largest beneficiaries of the Lesotho Highland Water Project are in the Gauteng and they do not clean the water well enough to allow low cost recycling downstream (Volume I).

New developments in the Waterberg and Limpopo require new water transfer schemes. The demand for additional water cannot be avoided and the inevitable economic response is increased charges for water and the setting of limits to use.

The demand for economic growth therefore determines the supply of water. The cost of water for economic and social development is indicated Table 1. Water cost is linked to energy cost. For example high salt wastage ion exchange, could be substituted with higher energy consuming reverse osmosis. Sustainability of energy consumption and production systems therefore affects the availability of water. In spite of the water shortage there are large scale unaccounted for losses in urban infrastructure (see Table 8), Agriculture can obtain water for free by uncontrolled pumping from the river and water transfer systems (Volume I). Alternatively agricultural production can obtain water at very low costs (in Table 1.

Table 1 As a result agriculture does use waste minimization techniques such as night time irrigation. The allocation of charges for water is therefore a key factor in sustainable use of water supplied by the integrated South African water transfer system.

5.2 Salt and waste water storage and disposal requirements exceed capacities of underground compartments in coal mines, and above ground ash dumps and brine-ash co-disposal sites

Although definitive data by way of increased leakages have not been provided, the need for safe disposal is illustrated by the increasing water inventories, and the need for further research on capacities and final locations for the salt flows.

The search for alternative storage sites on the processing industry sites and disposal sites on the coal mining industry sites indicates that the need for additional safe capacity (see Sections, 4.1, 4.2, and 4.3). A more systematic and integrated approach to the mine water salt problem is recommended. It is proposed that this approach will focus on the economic and environmental incremental improvements from Integrated Eco-efficiency projects.

5.3 The permitting system for water usage and salt storage and disposal may encourage the irresponsible transfer of liabilities

The Governance study has identified a number of situations where liabilities are transferred from one institution to another without a clear understanding from all parties. Examples are

- Integrated Life Cycle identification of the lowest cost and most environmentally beneficial options do not appear to have been made in the determination of the quantities and quality of mine water to replace raw water.
- Guidelines for safe disposal and storage at existing ash dump sites have not been published by the DWA. So there is no public consensus on what is safe and how the site should be reported.
- Comparative risks and costs of disposal options are not available to the DWA. This includes integrated options.
- Integrated Eco-efficiency projects require demonstration of incremental economic benefit and incremental environmental benefit. These economic benefits were not clear during the assessment of the inventory.
- There appears to be uncertainty on the allocation of liabilities if the waste from one industry is mixed with that from another industry. This increases the uncertainty of project viability and may be eliminating options that would otherwise be viable.
- It is not clear whether the water permit for Sasol Synfuels and Eskom Tutuka to replace raw water with mine water is economically sustainable. For example, it appears that the bulk of the cost and risk is taken by the processing industry. But the main cause for the salt load is in the underground mines. More sustainable options might be reductions in salinity of mine discharge water. Three techniques recommended by WRC are ground water pumping to avoid inflow to the working areas, and housekeeping underground, e.g. keeping fissure water separate from mine water, and pumping from the working areas rather than from the long term storage areas.
- Permits in the case study area had not been finalized 10 years after the NWA. This creates uncertainty on the scale of environmental liabilities and may eventually transfer liabilities to the state should a mine become economically unviable, without adequate provisions for post closure remediation.

6 SUMMARY AND DISCUSSION

The study identifies two Integrated Cleaner Production projects to recycle mine water to replace raw water demand in processing industry. Both projects reduce demand for clean water, but do not demonstrate improved environmental performance.

Measurements of environmental performance by long term trends of salination in the surface water system indicate increased loads due to mining and processing industries. Also observed, but not fully reported in the inventory study are the trends of changing pH which appear to follow the life cycle of mine water salination, i.e. increase at the commencement of mining activities, peak and fall to lower pH with time. These have not been correlated with neutralization potential of rock overlay and this can be an aspect for further enquiry with the coal mines.

As integrated Cleaner Production interventions have been implemented in the case study area, the case study is well suited to the intentions of the project, i.e. identifying success factors and barriers to using integrated Cleaner Production technologies. The interventions are controlled by DWA via water use permits with 5% to 10% of the raw water demand being reduced. In the Cleaner Production hierarchy these end-of-pipe solutions which recycle and dispose of the waste are usually less efficient but lower cost less than avoidance and minimization technologies which tackle the environmental problem earlier in the production system. There less water is contaminated and the treatment problem is reduced, and the waste problem is less. In the mass balance models set up for the case study area 537 t/d of salt are due to mine water and water treatment chemicals. The daily load in the industrial component of the study area is calculated from the mine water discharges, plus the processing industry salt production, to be 581 t/d. Treatment chemicals make up about a quarter of the total load. Full details of the calculations are provided in the Volume II.

Avoidance and minimization solutions were raised during discussions with the mining industry. One technology in use is the minimization of fissure water flows by designing surface water flows above the mine compartments so as to discourage trapping of water in depressions and thereby increasing run-off. Avoidance and minimization strategies have been identified by WRC, i.e. minimizing the fracturing of strata that are associated with long wall mining (Hodgson & Krantz, 1998);draining working areas to avoid fresh and reactive sulphide contact with fissure water, immediate pumping of fissure water from the working areas to the surface; and separation of fissure water flows from mine water (Pulles et al., 2008a; Pulles et al., 2008b). The WRC has prepared a series of guides for water management in mines. Industry has also tested avoidance and minimization strategies but found them economically non-viable (Volume II).

The sustainability of the desalination technology solutions have been compared by a life cycle assessment. Savings of 4 to 5 times salination for boiler feed water can be achieved in the complex by switching from Ion Exchange (a positive feedback desalination technology) to Reverse Osmosis (a zero feedback technology see Volume IV).

Both the Inventory and the Technology reports recommended Life Cycle assessments for comparison of integrated technology options. Boundaries of the Life Cycles are inside the complex boundary, but over the individual company NWA Section 21 permitted boundaries.

Integrated solutions are not possible unless the technical problem is defined from an integrated analysis of the chemical processes and flows through the different industries in the complex. There are two approaches to identify for integrated projects; integrated Cleaner Production and integrated Eco-efficiency projects. A discussion on the differences between these is provided in the Inventory report (Volume II). Eco efficiency includes aspects of economic sustainability and is preferred.

The main finding for this study is that the long term increasing trend for unaccounted salt flows to the surface water systems indicates control of salt storage and disposal is the key factor for environmental sustainability. The economics of desalination and waste storage are driven by the cost of water and the management of post closure liabilities. These two parameters are controlled in the governance system for clean water conservation, and mine water production which is the main source of salts. A key weakness in the governance component appears to be the absence of public data on relative techno economic and environmental performance data for alternatives identified by stakeholders in the complex. Research is currently system specific, proprietary and therefore uncoordinated. Findings on capacities and leakage are not reported in the public domain. Reasons are understandable given the liabilities that are involved, but the threat of long term pollution is a public concern and the responsibility for ensuring a long term working system falls under the NWA and Department of Finance.

Experience of government and mining industry in the adjacent Olifant's catchment for three case studies involving different governance, economic, and sustainability approaches has been reviewed by Hobbs . They are the Brugspruit Water Pollution Control Works (BWPCW) serving the northern portion of the Witbank Coalfield; the Emalahleni Water Reclamation Plant (EWRP) serving the AngloCoal and Ingwe Collieries southwest of Witbank; and the Control Discharge Scheme (CDS) which uses the available assimilative capacity of the Upper Olifant’s River systems and stores and treats mine water prior to licensed and coordinated discharges during periods of high river flow. A summary of the key technologies and performance factors is provided in Table 9. More information on the project can be obtained from Hobbs (Hobbs et al., 2008), and Günther (Günther, 2011; Günther et al., 2006). What emerges from the published data is an apparently successful cooperation between DWA and Local Government, and Mining Industry, to develop a sustainable water reclamation Eco-efficiency project. The planning horizon of the Anglo Operations Limited registered owner is 20 years, and the costing and contracting for the legal rights to water, waste disposal permitting, and two main clients is complete.

The learning from this WRC study project is confirmed by the case study analyses of the three projects in the Oliphant’s Catchment. The high level approach should be changed from Cleaner Production to Eco-efficiency. This will allow the development of an economic model for the project. The other learning from the EWRP project which is similar to that in this project, is the need to develop cost effective desalination and water treatment technologies at a cost that consumers are willing to pay. The costs for the long term supply from the EWRP plant in 2011 (from R 4.85/kl) are comparable with those of the Rand Water Supply in 2007 at R 3.60 (see Table 1), and the highest cost for water purchased by Eskom power generation in 2007/8 at R 2.43/kl. It was expected in the inception report for this project in 2008 that Rand Water costs would be doubled by around 2012 due to the electricity cost component was expected around R 1/kWh by 2012. This forecast on electricity price has since been proven correct. So the economics of water recovery as well as the security of supply and the need to protect for post mine closure liabilities indicates that an integrated project might be economically viable in the near future. Pre-commercial directed research has the highest chance of implementation and it is recommended that WRC continue inventory in this research theme using case studies in cooperation with industry and the responsible authorities.

Another consideration is the establishment of the boundaries of the water quality problem. This will give clarity on the post closure liabilities, and assist with the techno-economic evaluation of water recycling options. The key aspect question is: “Are the long term trends of water salination and pH changes caused by undisclosed point source leakages or by unidentified non-point source and uncontrollable above and below ground leakages?”.

The issue of building trust has also been highlighted by the Emalahleni Water Recovery Works project in the presentation “Building Relationships of Trust-what we have learnt from Emalahleni that will guide us into the future” (Günther, 2011). The EWRP learning is that the “key to successful engagement is early and sustained consultation”. If that learning is correct, then what is needed now is an economically viable technology and business plan.

Table 9: Experience with Integrated MW desalination projects in the Oliphant's Catchment

Water treatment project	BWPCW	EWRP	CDS
year of most recent data	2007	2011	2007
Source of data		(Günther, 2011; Hobbs et al., 2008; Günther et al., 2006)	(Hobbs et al., 2008)
Owner	AOL	DWA/Mpu	DWA
MW capacity built (Ml/d)	10	30	all participating mines
% capacity	not working	99%	all participating mines
Surface water discharge (Ml/d)		< 7	all participating mines
PW capacity (Ml/d)	N.A.	25	N.A.
% achieved	0	97%+	all participating mines
MW capacity potential (Ml/d)	10	30/50/75	all participating mines
Treatment technology		CSIR pre-treatment limestone/lime, gypsum pptn., filtration, RO.	soda lime
Economic model: income and costs	Public facility	Integrated industrial project with Local Govt.	Lowest cost. Acceptable environmental impact
Benefits	Accepts defunct and ownerless mines decant	Potable Water sold to Emalahleni LM	Risk accepted by the state
	WW treated	Process Water sold to Mines	
		20 yr Project life	
		CPI escalations	
selling price (R/kl)	N.A.	R 4.85-R9.15	N.A.
Discharge fee MW (R/kl)		R 0 -?	
Waste management	regional facility on site disposal and discharge	Integrated industrial recycling plant and adjacent waste disposal sites	Each participant has its own treatment, storage, discharge and disposal facilities
Gypsum ($CaSO_4$)	sludge disposal	recovered for building material	sludge disposal
brines	evaporation dam	evaporation pond	storage for discharge
permitted river discharge	Yes (<100%)	Yes (< 22%)	Yes (<100 %?)
sludge disposal site	yes	yes if needed	yes
Construction cost	R 26.5m (1997)	+/- R300 m (2005)	> R 100m
Expected additional demand (Ml/d)	none	200	all participating mines

Abbreviations: PW	Potable Water
WW	Industrial waste water
MW	mine water
RO	Reverse Osmosis
pptn.	precipitation
AOL	Anglo Operations Limited
BWPCW	Brugspruit Water Pollution Control Works
EWRP	Emalahleni Water Reclamation Plant
CDS	Controlled Discharge Scheme

7 RECOMMENDATIONS FOR IMPLEMENTATION OF THE FINDINGS AND FURTHER RESEARCH

Further research on the development of integrated Eco-efficiency projects is recommended as follows:

- The main environmental sustainability problem appears to be how to change trends of positive feedback where more salt is stored than is removed for recycling of the water. A number of technology options have been identified during the project, and these should be tested using the life cycle thinking, and existing in house and public data.
- The main governance problem appears to be how to ensure that all parties gain from the integrated projects. It is proposed that security of supply of water, and economic viability are the two key success factors. Economic viability includes post closure liability calculations. Technical options and an approach are provided in the Inventory report and the integrated Cleaner Production technologies report.
- A key factor in establishing environmental sustainability is an understanding of the leak rates, disposal capacities, and costs of the candidate disposal technologies. These should be available to industry and the Authorities so that viability of projects that increase salt loads can be assessed.
- Identify technologies that reduce inventories rather than build inventories. It is recommended that the current inventory model be verified with site specific flow data, e.g. evaporation rates and evaporation areas are measured not estimated, and the unidentified sources of salination or the surface water flows are located. For example, the current inventory model is not linked to the mine water decant and leakage models, and has been ignored from the current mass loading calculations.
- The water resource problem can be tested with learning from the research and development of carbon reduction technologies and governance instruments. For example, South Africa has developed experience at the line government departments and treasury on minimizing of carbon loads via incentives and progressive taxes.(National Treasury of South Africa, 2010). Those incentives models could be evaluated to see if there are incentives for new technologies that reduce the risk of salination. This will meet economic sustainability condition for the proposed integrated Eco-efficiency approach.
- A pilot study or previous research data can be tested with the Mass Flow Analysis data set and stakeholder participation and understanding developed from this project. It would be proposed that previous technology evaluations be reviewed with the boundary conditions and potentials for reductions of salt storage identified from the Mass Flow Analyses. It is expected that, for example, the extension to avoidance and recovery salt recovery technologies would provide the opportunity for a more robust problem and solution assessment than previous salt storage research (K5/1669/3 2008 and K5/1669/3 2008)
- A learning model is proposed where understanding of the factors that benefit and reduce the sustainability of the complex are shared with industries and authorities. There are several aspects
    - o Understanding the effect of two competing regulatory systems for water and salt management in the Mining Sector. Underground storage of mine water in areas that have practiced long wall mining may have leakage to the surface

water systems. Best practices for sealing and flooding apply to sealed mines. The option for long term pumping to avoid leakage is not considered to be a sustainable solution. Any reports on this option have also not been made available to the study.

- Understanding of the sustainability of the economic system that currently drives water pricing, and thereby determines the economic viability of water conservation and pollution prevention, and treatment options in the complex.
- Understanding how perceptions change due to provision of performance data from the technical components of the project, and how these affect consensus on a Desired State for the complex.

Pilot project and case study data are recommended for multidisciplinary research. These have main advantage that the reality of the problem is defined as precisely as is possible with site specific data.

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