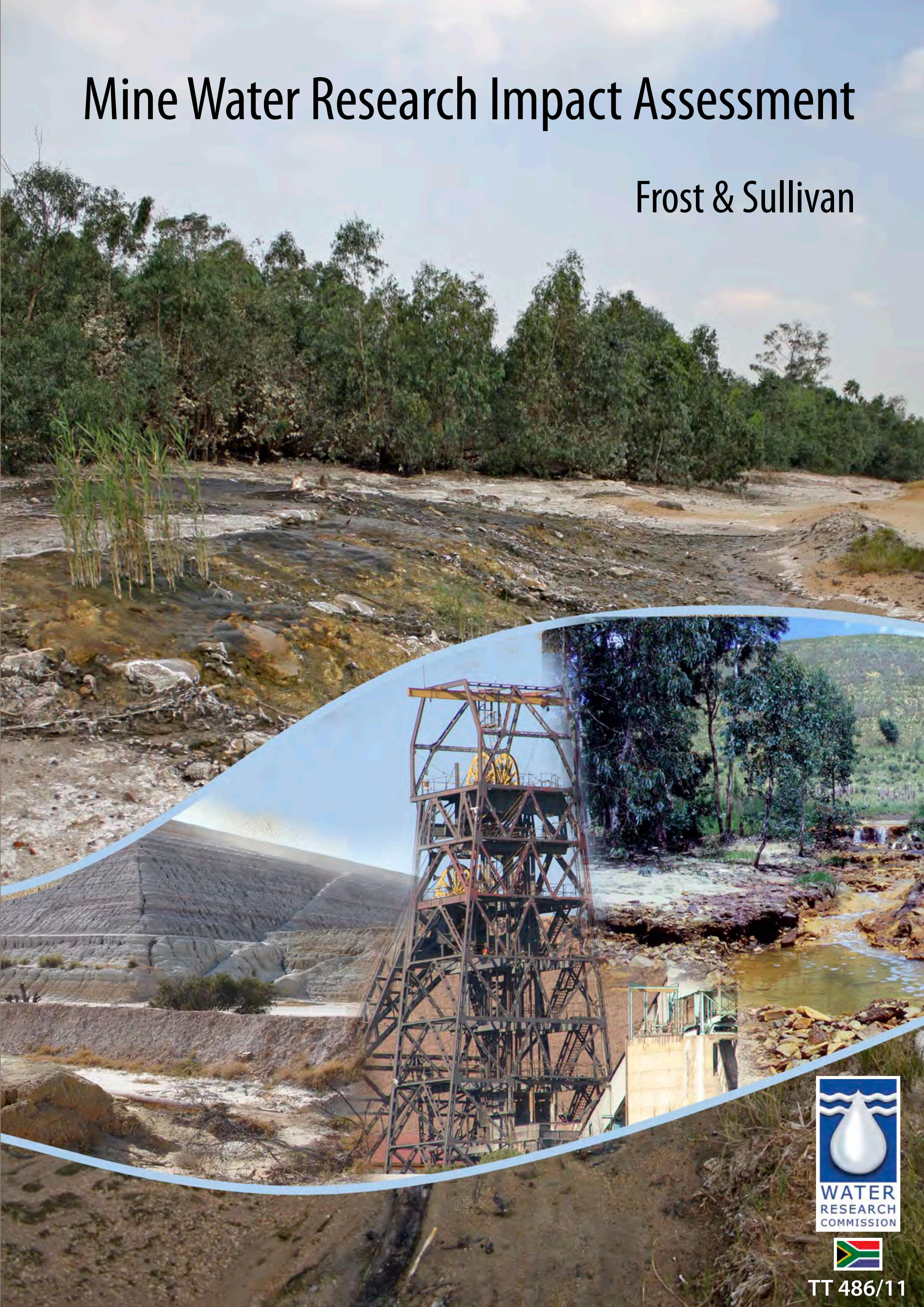
Mine Water Research Impact Assessment

Frost & Sullivan



WATER RESEARCH COMMISSION

TT 486/11

Mine Water Research Impact Assessment

Report to the
Water Research Commission

by

Frost & Sullivan

WRC Report No. TT 486/11

August 2011

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031

The publication of this report emanates from a project entitled *Mine Water Research Impact Assessment* (WCR Project No. K8/831)

DISCLAIMER

This report has been reviewed by the Water Research Commission (WRC) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the WRC, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ISBN 978-1-4312-0115-0
Printed in the Republic of South Africa

Table of Contents

1. Introduction

Formal mining has been in existence for approximately 120 years in South Africa. The country is reported to have an estimated 10 000 km^3 of hydraulically interlinked mines in Mpumalanga alone, with approximately 300km of interlinked gold mines on the Witwatersrand. Most of these mines started operating at a time when legislation did not take into consideration the need for environmental management and mine rehabilitation. Thousands of mining operations have been left unrehabilitated and abandoned as a result of inadequate resources and changing market forces.

The Department of Minerals and Energy's abandoned mines database has recorded more than 4 770 unrehabilitated and ownerless mines across the country. These mines have become the responsibility of the state and are a potential threat to air, soil and water, and thus the health of the communities around them. The pollution of South Africa's scarce water resources through mining is a significant challenge facing the country.

The Water Research Commission (hereafter referred to as WRC) has been extensively involved in mine water research since 1989. This organisation is a statutory institution established in 1971 by an Act of parliament. The WRC represents a dynamic hub for water-centred knowledge, innovation and intellectual capital. It provides leadership for water-related research and development through the support of knowledge creation, transfer and application. To date the WRC has produced approximately 39 research studies that focus on mine water management, which typically considers water requirements and the pollution potential of South African mines.

In an effort to retain and strengthen its position as a "value for money" institution delivering research and innovations that contribute to socio-cultural, economic, political, technical and environmental aspects in South Africa, the WRC has embarked upon a number of studies to assess and portray the impact of its research programmes and resulting products and their benefits to the country.

The WRC has limited capacity to conduct such evaluations hence it has commissioned international growth consulting company Frost & Sullivan to support on a review of selected research products / programmes one of which is within the area of mine water related research.

1.1. Aim and Objectives

The aim of this project is to provide the WRC and its stakeholders with a concise assessment (to date and future potential impact) of WRC mine water related research investments and products on socio-cultural, economic, political, technical and environmental aspects of South African society.

In the context of the above aim, the project objectives are outlined in the figure below:

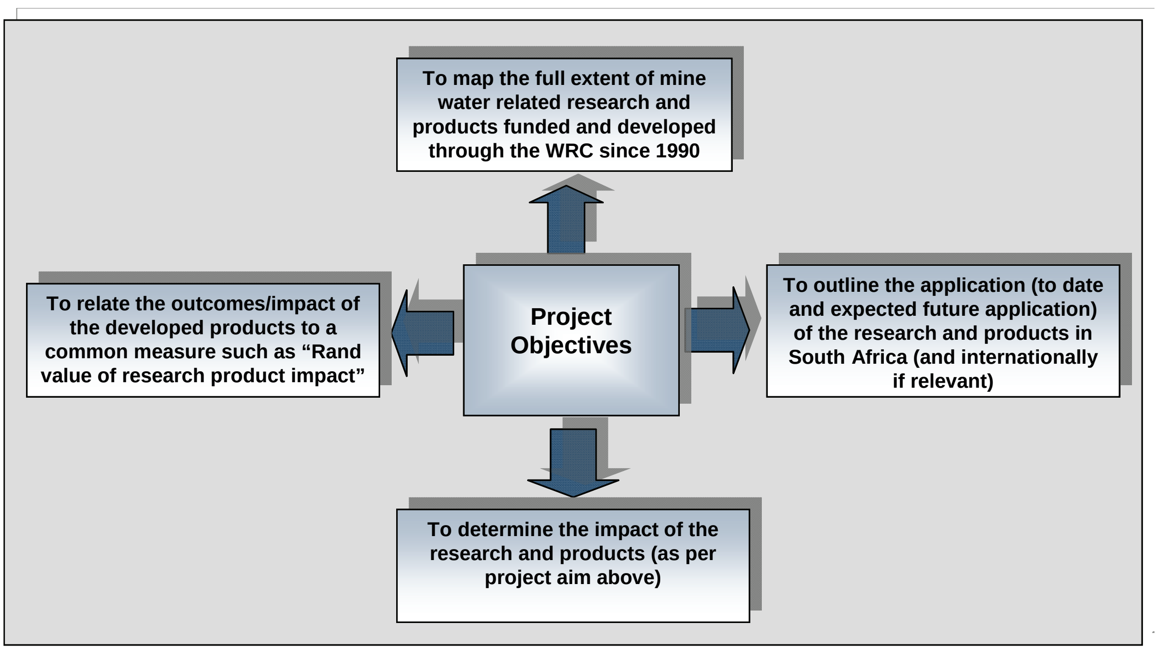


Figure 1: Project Objectives

1.2. Project Scope

This project analyses research studies conducted by the WRC that are related to mine water management. Subjects within the broader context of mine water research include contaminated land, surface and ground water as well as various pollutants arising from waste mine dumps and defunct mines.

The research studies analysed focus on case studies of various mines located throughout South Africa. These include, but are not limited to gold, uranium and coal mines.

The project scope is limited to categorising the applicable research conducted by the WRC and mapping the full extent of this research using a timeline from the year 1989 to 2008. The research scope includes reports, publications, methodologies, software guidelines and patents.

1.3. Project Methodology

The project was carried out using primary research (telephone or face-to-face interviews) as the principal method of data gathering, supported by secondary research (published and online material).

The focus of the interviews predominantly included the respondent types outlined in the figure below.

Primary Participants *

Interviews with primary participants involved:

- **Mining company engineers (7)**
- **Environmental consultants (7)**
- **Water treatment companies (3)**
- **Government organisations (5)**

Total interviews: (22)

Other Respondent Groups *

Interviews with other participants involved:

- **Academics (4)**
- **Technology providers (2)**
- **Non-governmental organisations (3)**
- **Individuals (3)**

Total Interviews: (12)

Total interviews: 36

* **Most respondents were contacted on more than one occasion to verify specific information and data**

Figure 2: Project Methodology

2. Background to Mine Water Research

2.1 The History of WRC Mine Water Research

The WRC has been conducting mine water related research for over ten years. The research conducted is typically case study based, where a certain number of mines are selected to represent the area of study. The research is conducted with specific end user groups in mind. These range from the general public to mine engineering staff, practitioners and specialists. The earlier research projects dating back to the year 1989 were based on gold and uranium mines. The focus areas of these studies were water requirements and pollution potential of these mines.

Subsequent research projects between the year 1995 and the year 2000 focused on issues such as the impact of mining on the surface water environment, treatment options for mine effluents and the rehabilitation of mine soils. Between the year 2000 and 2005 a significant amount of research was conducted on modelling techniques and predictive tools. The studies in this period tackled issues such as industry wide water balance, development of low cost passive water treatment systems and water modelling systems for the mining industry.

From the year 2005 the WRC extended its scope to coal mines and acid mine drainage where it focused on predictive tools for long term water quality management in underground collieries as well as the quantification of the potential and magnitude of acid mine drainage under South African open cast conditions.

Regional Mine Closure Strategy

In 2005 the Department of Minerals and Energy developed and subsequently implemented a regional mine closure strategy for hydraulically linked mines following a significant array of research conducted by the WRC dating back to the year 1989 on mine water. Specifically, the WRC published a report on mine closure strategy entitled '***The development of appropriate procedures towards after closure of underground gold mines from a water management perspective'***, which made an important contribution to the DME closure strategy. The premise of the mine closure strategy was that most mines are hydraulically interconnected with adjacent mines. As such the closure of one mine within the region will often have impacts on the remaining mines. The last mine to cease operations in the region also ran the risk of bearing the cumulative burden imposed by all the other mines that ceased operations before it. The mine closure strategy thus assisted in providing an equitable basis to share responsibility between neighbouring mines in the same region. It also contributed to long term plans to deal with the legacy of poor quality water from mines.

The mine water related research conducted by the WRC has been categorised into three groups:

Water Modelling Techniques and Predictive Tools Research

The main focus of research studies in this area have been modeling techniques and predictive tools used to analyse and better understand mine water and mine water related issues. The projects have helped develop water modeling systems for the mining industry, tools used for information transfer for mine water quality management as well as the development of predictive tools for issues such as the controlled release of saline water during periods of high river flows.

Contaminated Land and Surface Water Research

These projects have helped to increase the understanding and knowledge around mine water and mine rehabilitation techniques. They have focused on contaminated land and surface water, point source effluent treatment as well as issues regarding soil covers for mine waste dumps.

Water treatment of Acid Mine Drainage

The projects in this segment have focused on providing a good understanding of acid mine drainage (AMD). The projects provide clear definitions of AMD, is constituent components, methods of formation and impacts on the environment. The projects also outline remedial measures that could be utilised to circumvent AMD by way of methods such as neutralization.

Regional and Interconnected Mine Water Research

Research projects in this segment have contributed to a better understanding of issues involving interconnected mine water, regional mine water as well as mine closure. The studies have focused on pollution of interconnected mine water and have brought to light liability concerns regarding mine closure. They have resulted in the provision of an equitable basis to share responsibility between neighbouring mines upon closure and ultimately these research studies have contributed to the long term plans to deal with a legacy of poor quality water from mines.

The WRC has completed 60 mine water projects since 1989 as shown in Figure 3 below. There are also a number of ongoing projects that are not reflected or considered in this study. Details of all project titles and aims are located in the appendix. The associated impacts of these research studies will be discussed in more detail in the remainder of this document.

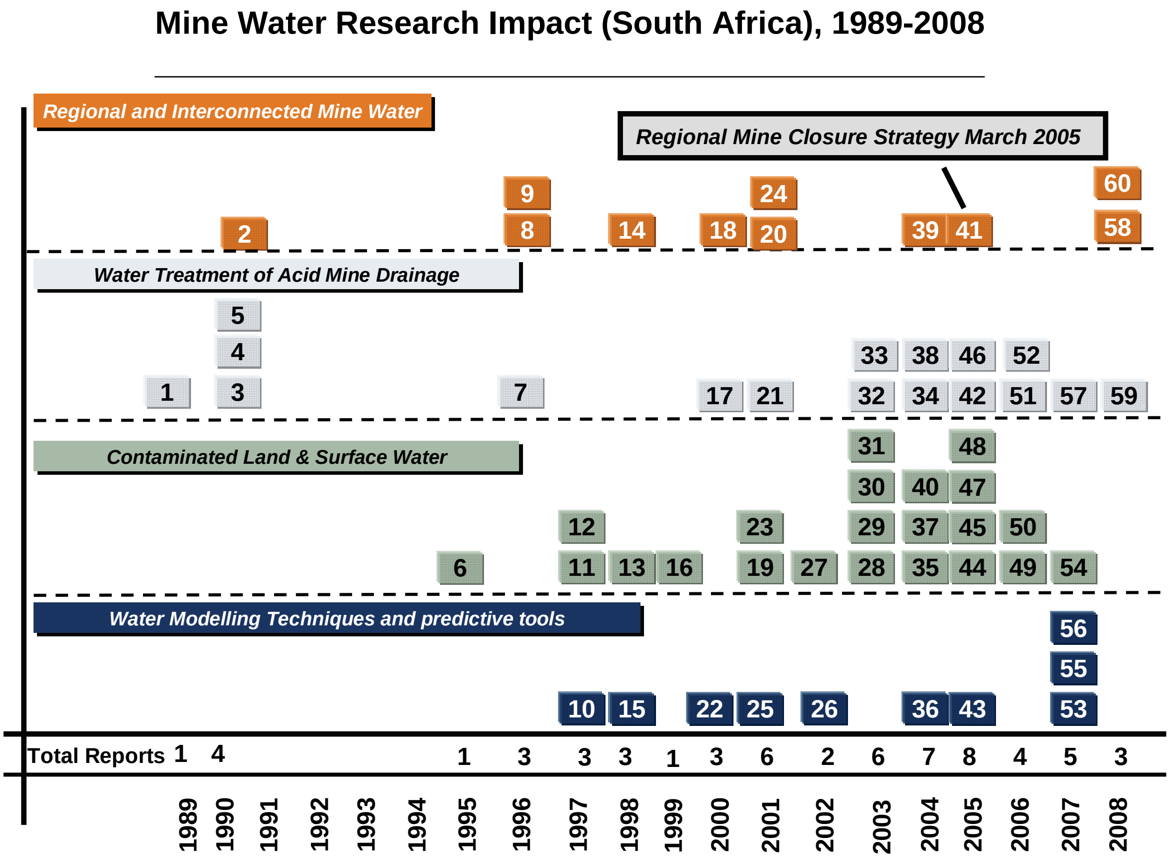


Figure 3: Mine water research conducted by WRC

3. Impact of Mine Water Related Research in South Africa

Overview

The WRC has conducted mine water research on a wide range of topics in South Africa. The research studies they have conducted can be placed in 4 broad categories namely Regional & Interconnected mine water research, water treatment of acid mine drainage, contaminated land and surface water research and water modelling techniques and predictive tools research.

The application of the findings from these studies by industry has significant economic, environmental, social and health impacts. Both primary and secondary benefits can be derived from theses four impact areas. Primary benefits to society are directly attributable to research findings from the WRC while secondary benefits are an indirect result of WRC research on mine water.

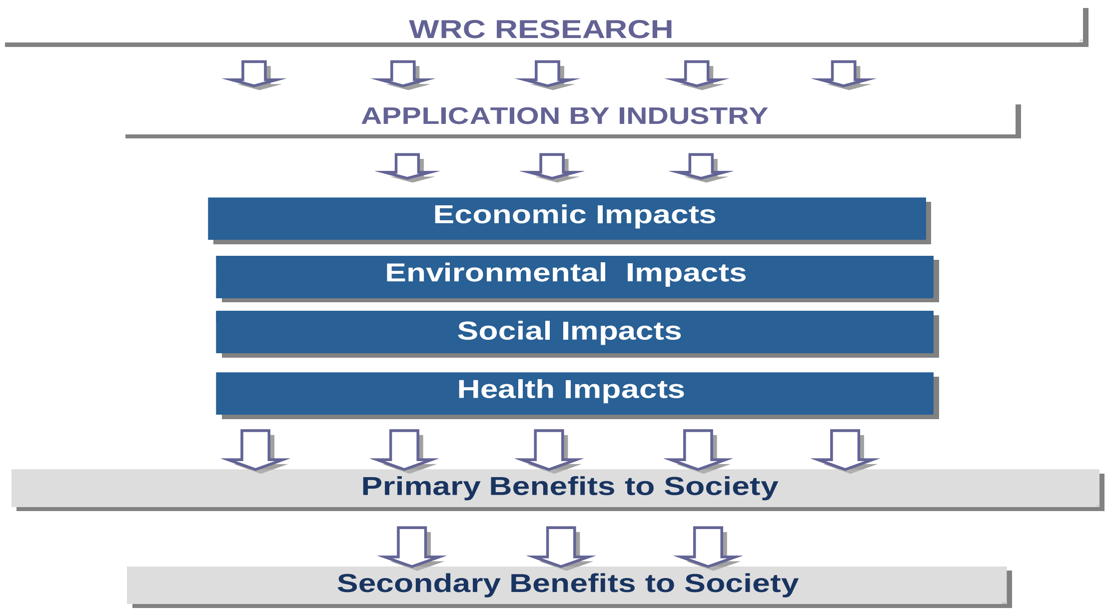


Figure 4: Overview of Impact assessment

3.1 Assumptions

Impact assessment, particularly related to research and specific activities, can be a challenging and sometimes subjective process. In light of this, this project has aimed to utilise a common quantifiable measure that is both relevant and measurable across the four impacts areas, namely economy, environment, society and health.

For this reason, a focus of this project was to try and quantify each impact identified across the impact areas. This was not always possible, owing to the qualitative nature of some of the research areas, however where possible this was conducted.

3.2 Impacts

Impacts of WRC funded research have been analysed using a qualitative and quantitative approach.

The **economic** impacts analysed in this document refer to economic aspects such as revenue generation and cost saving. These impacts represent the current and potential benefits of WRC research on society and South Africa as a whole.

The **environmental** impacts analysed refer to the impact that mine water has had on the environment. An analysis of research conducted by the WRC to ameliorate these impacts is then conducted, following an examination of the current and potential benefits of this intervention both in a quantitative and qualitative manner.

Social impacts looked at the direct and indirect impact of WRC research and associated environmental issues on society. Both primary and secondary benefits to society are analysed in detail and an analysis of the implications of these impacts on South Africa.

Health impacts analysed those aspects of mine water management that affect the health of the community. An impact assessment of WRC research on these health issues is conducted and the benefits attributed to society are detailed.

The impact analysis is not comprehensive in the sense that it quantifies all economic, environmental, social and health impacts attributable to WRC research. Rather, examples of the impacts are quantified in order to provide an indication of the impact. For some of these examples the link with WRC research is generic in nature and not linked to the findings or a single group of projects

Table 1: Impacts of mine water related research in South Africa

Economic	Environmental	Social	Health
			
❖ **Revenue Generation** ❖ **Industrial Materials** ❖ **Cost Saving** ❖ **Water Treatment**	❖ **Reduced degradation of soil quality** ❖ **Prevention of surface water contamination** ❖ **Limited groundwater contamination**	❖ **Reduced pollution of farming land** ❖ **Limited pollution of surface water** ❖ **Improved quality of drinking water**	❖ **Reduced incidences of loss of life** ❖ **Less cases of absenteeism from work**

3.3 Economic Impacts

3.3.1 Introduction

In South Africa's effort to stimulate economic growth, increased production and revenue generation have become critical elements in generating growth. However, this growth can only occur through the development of expertise through research and training. It is thus important that organizations such as the WRC develop and test new and creative ideas. This leads to increased innovation, economic activity and sustainable economic growth. Significant economic benefits can thus be derived from WRC funded research; these include revenue generation, water treatment, industrial materials and cost saving. The benefits of these impacts that are further investigated in this study are detailed below.

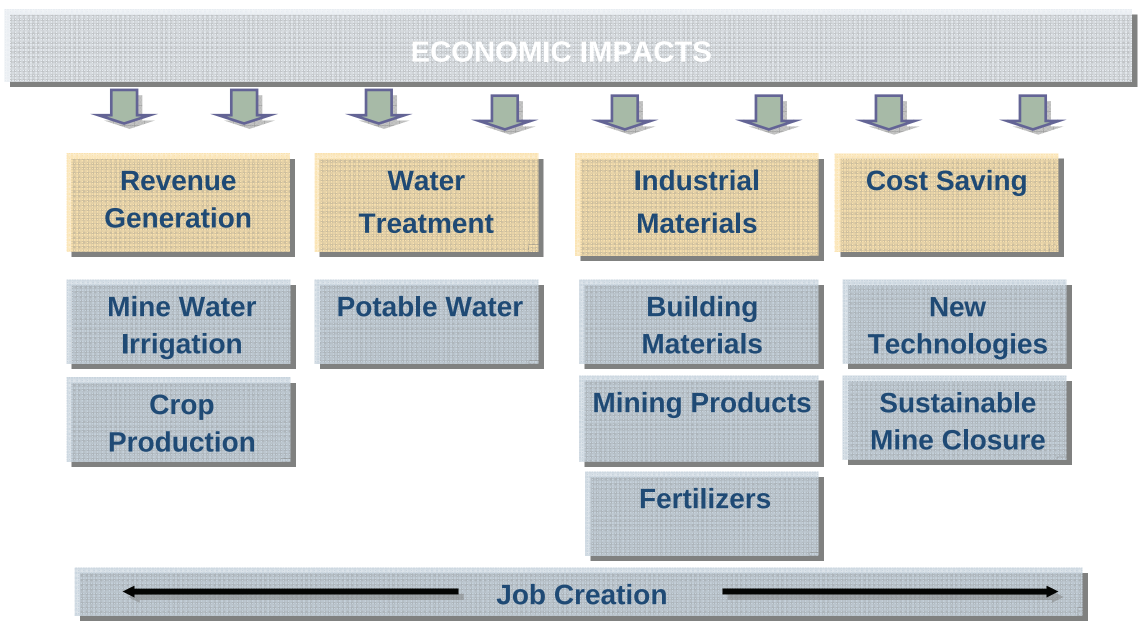
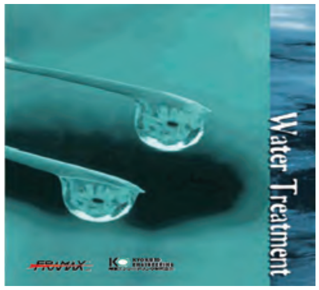


Figure 5: Economic impact assessment overview

Table 2: Overview of Economic impacts

Revenue Generation		Beneficial revenue generating projects have either arisen directly or indirectly as a result of WRC research. WRC funded projects have shown that crop irrigation using mine water can be profitable, environmentally friendly and economically sustainable. WRC research has envisaged the potential benefits of increased productivity at a regional and country level due to commercial crop production on a large scale using mine water for irrigation.

Water Treatment		Research findings from studies conducted by the WRC on water balance models, water treatment technologies and environmental rehabilitation are used as baseline information by industry participants. Significant players such as engineering consultants, mining companies and mining consultants save millions of Rands in research time by utilising WRC research as baseline information in setting up projects such as water treatment plants. Significant benefits can thus be attributed to society from water treatment projects such as provision of clean piped water, and dust suppression for communities living in and around the mining areas.
Industrial Materials		WRC funded projects not only result in direct impacts but indirect impacts as well. Use of their research by industry in metal removal processes, water treatment processes and environmental rehabilitation processes produces useful industrial materials. By-products such as gypsum produced from water treatment processes can be used to manufacture building materials, fertilizers, and mining products. Other industrial materials such as ferrite recovered in metals removal processes can also be sold on the industrial market or used in other mining operations.
Cost Saving		Cost saving benefits can be derived from projects funded by the WRC and conducted in collaboration with participants such as universities and mining companies. Such projects focus on the development of new technologies and improvement of existing technologies. Technologies such as the BioSure process have allowed municipalities to transfer sewage sludge to mining companies for use in water treatment processes. This ultimately gives municipalities a significant cost saving in sludge handling costs and mining companies with a cost effective technology to treat acid mine drainage.
Job Creation		Jobs are created across all the key areas mentioned above as economic impacts. Revenue generating projects such as mine water irrigation require additional labour to meet increased production of crops. Industrial projects such as building of houses using gypsum building materials also require significant amounts of labour. Water treatment projects require labour for the efficient operation and management of the new water treatment plants.

3.3.2 Quantification of impacts

REVENUE GENERATION

Mine Water Irrigation

The potential of gypsiferous mine-water for use in crop irrigation was evaluated in South Africa by the WRC in 1983. The major findings of research conducted by the WRC supported the use of mine water for irrigation, showing that in the short to medium term (eight years) irrigation with gypsiferous mine-water proved to be sustainable with a negligible impact on ground water.

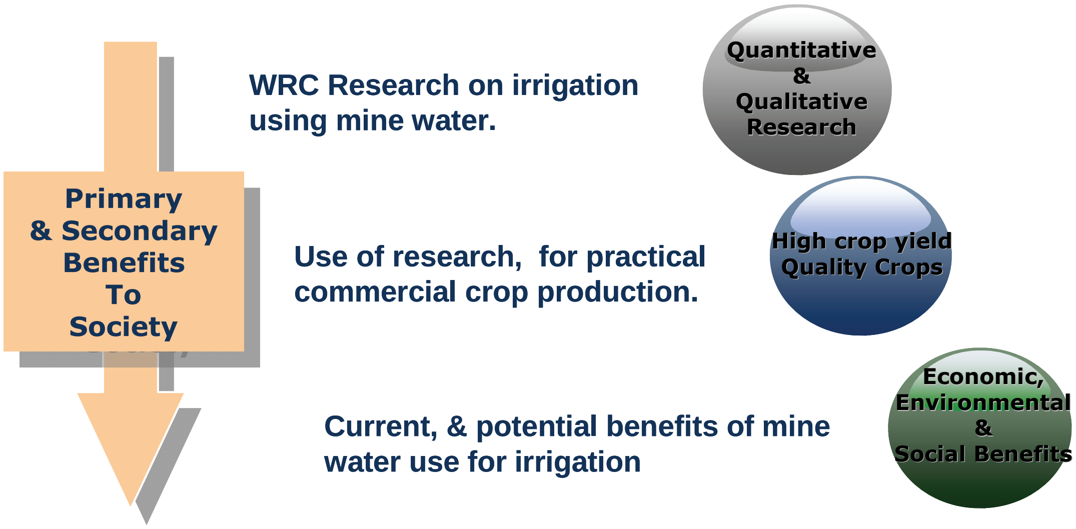


Figure 6: Mine Water Irrigation Overview

Crop Production

As part of a WRC funded mine water irrigation study, two commercial crops, maize and potatoes were grown on Smith Bros Farm. Good yields were recognized for both crops proving that commercial production of crops under irrigation with gypsiferous mine water is feasible and highly productive. An output of 65 tons per hectare for the potato crop was realized on 80 hectares of the farm. And this was then sold at R12.5 per 10 kilograms against input costs of R45 000 per hectare. The farmer Mr Niel Smith highlighted the fact that the potatoes grown using mine water were of the highest quality he had ever reaped; further strengthening WRC's findings that gypsiferous mine water can be very productive if used for irrigation purposes.

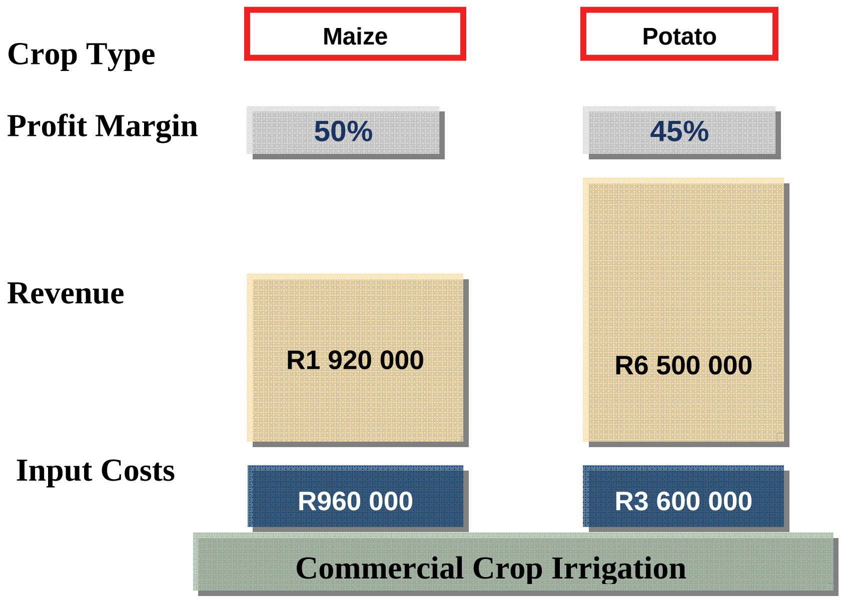


Figure 7: Revenue's generated from commercial crops

The maize crop had an output of 15 ton per hectare. This crop was then sold at R1600 per ton against input costs of R800 per ton. Mr Smith was also very pleased with the maize produce grown using mine water.

Table 3: Output of commercial crop

Maize Crop		
Input Costs	**Output /Ton**	**Revenue**
R960 000	1200	R1 920 000
Potato Crop		
Input Costs	**Output/Ton**	**Revenue**
R3 600 000	5200	R6 500 000
Total	**6400**	**R8 420 000**

Photo 1: Potatoes irrigated with mine water

"The potato crop irrigated using mine water was of the best quality I have ever reaped." – Farmer Niel Smith.

"I was also very pleased with the maize crop irrigated using mine water" – Farmer Niel Smith.

Photo 2: Maize irrigated with mine water.

Benefits of irrigation using mine water

Job Creation

- An additional labour force of 65 workers was employed to meet the needs created by increased production under irrigation. Each worker receiving a minimum of R5.20 per hour. Most of the additional labour was required for activities such as grading, washing and packaging of the potato crop.
- Over 500 additional jobs could also be created if agricultural opportunities using mine water for irrigation are exploited and more land is irrigated using mine water. This would be beneficial for the unemployed in the surrounding community who could earn a minimum of R5.20 per hour in wages.
- The drip irrigation system could be used in cluster farms near mines to produce bio-fuel crops and other agricultural produce. Such a move would result in job creation for the associated community.

Table 4: Additional labour employment

Additional Labor Employment		
	No Of Workers	**Salaries – Annual**
Current Staff	65	R648 960
Potential Staff	500	R4 992 000
Total	565	**R5 640 960**

- Areas such as Mpumalanga are short of water. It is in such regions that the use of mine water for the purposes of irrigation could be very beneficial and effective if the mine water represented a surplus resource – see box below for implications for South Africa.
- In addition to low quantities of water, some of these regions are also characterised by high temperatures and little to no frost. This makes these regions ideal for the most productive application of small plot farming for bio-fuels using the drip irrigation system thereby ensuring efficient water use and high levels of incomes for the farmers.
- Research shows that drip irrigation is 85% efficient in terms of applying water to meet plant transpiration requirements.
- About 10 ton of maize can be produced from a group of small-lot farmers occupying one hectare by using the system of unbroken planting and harvesting combined with drip irrigation.

Implications for South Africa

The use of mine water for irrigation purposes presents benefits such as stabilization of dry land crop production thus enabling dry season production, whilst at the same time providing a cost effective method of minimising excess mine drainage. Large amounts of mine water could possibly be made available to the farming community and utilized for irrigation of high potential soils in the coalfields of Mpumalanga province where water resources are already under pressure. A significant number of jobs could be created thus benefiting the local community and ultimately South Africa as a whole. Since water resources are already under pressure, DWAF may not allow the use of mine water for irrigation, but rather require that the water is treated to standards which would allow use by users who are even more productive.

WATER TREATMENT

Introduction

The WCR has conducted extensive research on water balance models, water treatment technologies, and environmental rehabilitation. Research findings from these studies constitute information that ends up in the public domain. This information is then used as baseline information by engineering consultants, mining companies and mining consultants in setting up projects such as water treatment plants.

Potable Water

The Emalahleni water treatment plant was set up in Witbank, Mpumalanga in 2008. The main aims of the project were to supply the local municipality with clean water, prevent polluted underground water from decanting into the environment, and to prevent the coal reserves from being sterilized. The Emalahleni municipality was struggling to meet demands for clean water. A number of households had no access to piped water and the demand for water was as high as 120 ML per day. The municipality was however only licensed to draw 75 ML a day from Witbank dam hence there was a significant need for additional water supplies to meet the demand.

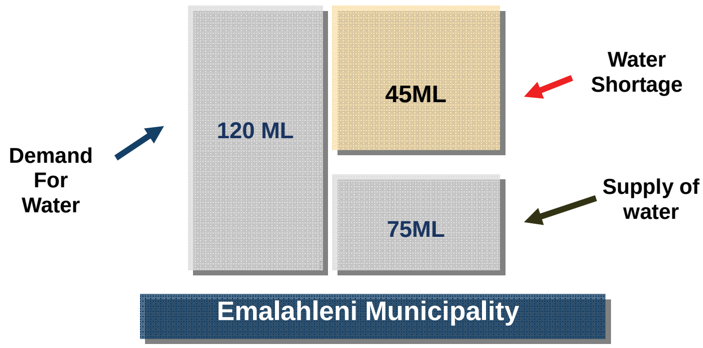


Figure 8: Water Demand & Supply Chart for Emalahleni Municipality

In order to relieve part of the municipality's water shortage, the water reclamation plant is currently supplying the local municipality with estimated 20 ML of water per day at a cost of R4.34 per kilolitre.

The balance of 5 ML water produced at the treatment plant is then piped to 3 collieries as well as several operations near a mining company's service department for domestic use and mining activities. As a result these operations are now self sufficient in terms of their water requirements which ultimately reduce the demand for water coming from the local municipality.

Photo 3: Emalahleni water reclamation plant

Figure 9: Water distributions from Emalahleni water treatment plant

Job Creation

- Establishment of the plant alone created 700 temporary jobs and about 40 permanent employment opportunities.
- An annual figure of 8 million Rand is being paid out in labor costs as a result of the water treatment plant.
- Numerous jobs for the surrounding community and even more jobs could be created as mining companies look into the numerous ways of utilizing solid and liquid waste generated from the plants processes

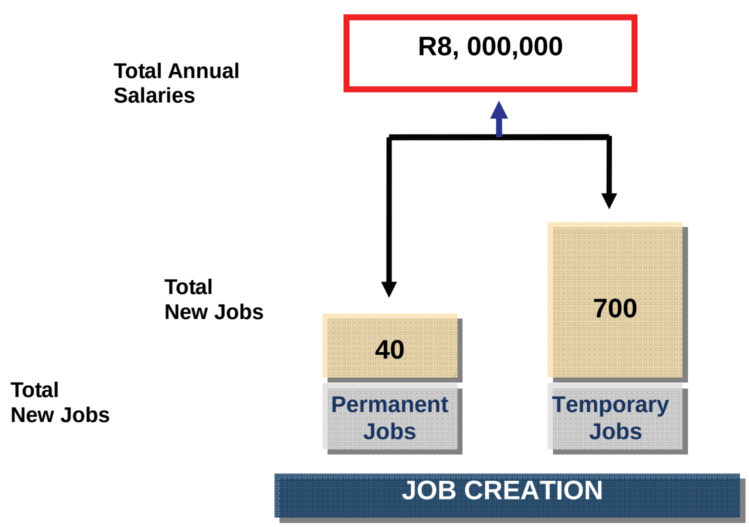


Figure 10: Jobs created from commissioning of water treatment plant

INDUSTRIAL MATERIALS

Introduction

The impacts of WRC research are not only direct but indirect as well. Application of WRC research by industry in various applications such as water treatment processes and metal removals processes result in the production of useful industrial materials. These materials which are usually by-products of the main processes can be used in other applications, re-used in the same application or they can be sold off as a commercial product.

The Emalahleni water treatment process currently produces 100 tons of gypsum per day as a solid by-product. This industrial material can be sold as a commercial product at R 221 per ton on the local market.

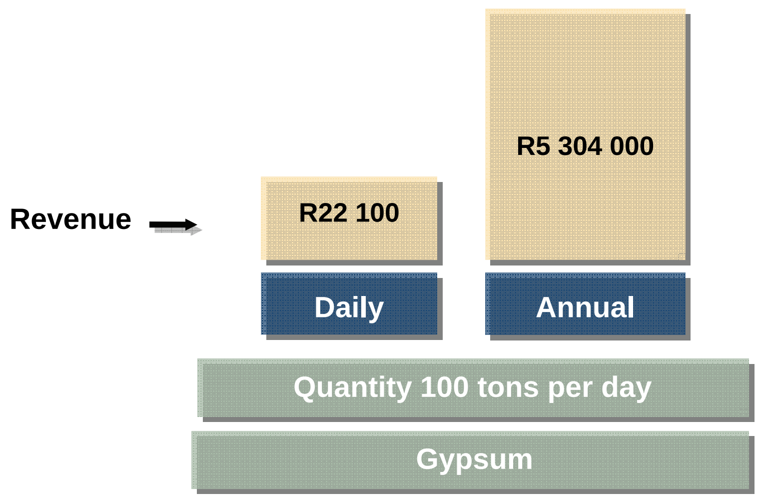


Figure 11: Revenue from gypsum

Mining Products & Fertilizers

- Two revenue generating projects under a certain mining company with a total value of R16 Million are in the final stages of completion. These projects are looking at converting gypsum waste produced from the Emalahleni water treatment process into pure by-products such as sulphur, or into building and mining products.

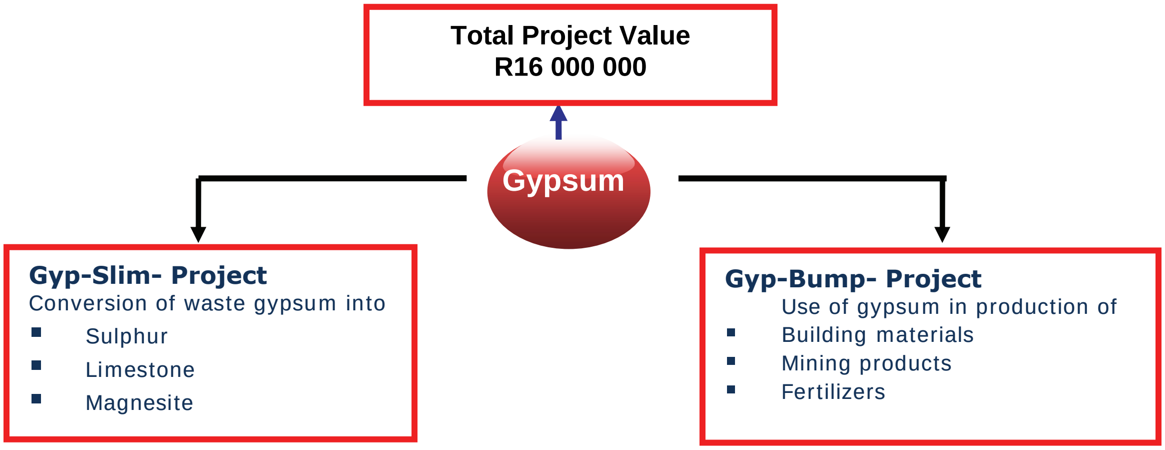


Figure 12: Gypsum By-Products

- Gypsum building materials have been used to build one house on a trial basis in Mpumalanga and this has subsequently received SABS approval for suitability of gypsum use in the construction of houses.

Building Materials

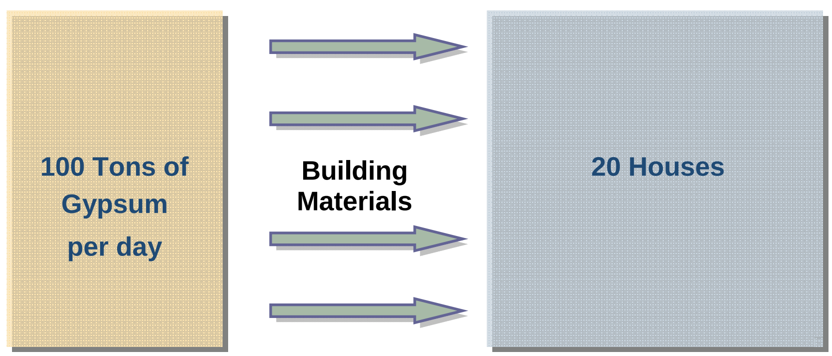


Figure 13: Gypsum building materials

- One 60 square meter 3 bedroom house requires about 5 tons of gypsum hence about 20 houses can be built from the 100 tons of gypsum produced by the treatment plant per day.
- The liquid waste produced can also be used to grow algae suitable for producing health products such as spirulina or for the production of bio-diesel.

Implications for South Africa

Establishment of the Emalahleni water treatment plant has greatly benefited society economically, socially and environmentally. The project has resulted in revenue generation from the sale of treated water, provision of clean piped water for the local community and it has created a significant number of job opportunities. The project has resulted in a sustainable, profitable and environmentally friendly method of disposing excess mine water which is ultimately beneficial to the country as a whole.

COST SAVING

Development of new technologies

The WRC has worked in collaboration with water treatment companies on projects that involve the development and implementation of new technologies. Of particular note is the BioSure water treatment project. This is a biological sulphate reduction process for treatment of acid mine drainage. The treatment process requires a biological substrate (sewage) which is obtained from Ekurhuleni municipality. The biological substrate is obtained free of charge for this specific use of water treatment, since this represents a cost saving to the water treatment works.

Table 5: Cost of municipality sludge handling vs. BioSure sludge use

Cost of Municipality Sludge Handling vs. BioSure Sludge use		
	Process	**Annual cost**
Municipality	Sludge handling	10,154,736
BioSure project	Water treatment	6,570,000

The water treatment plant is located near the sewage sludge handling plant hence the only costs involved in the treatment process are; electrical pumping, mixing costs as well as costs involved in the addition of the polyelectrolyte flocculent used in the water treatment process. After the water has been treated it is released into the river after going through the sewage works for aeration and polishing.

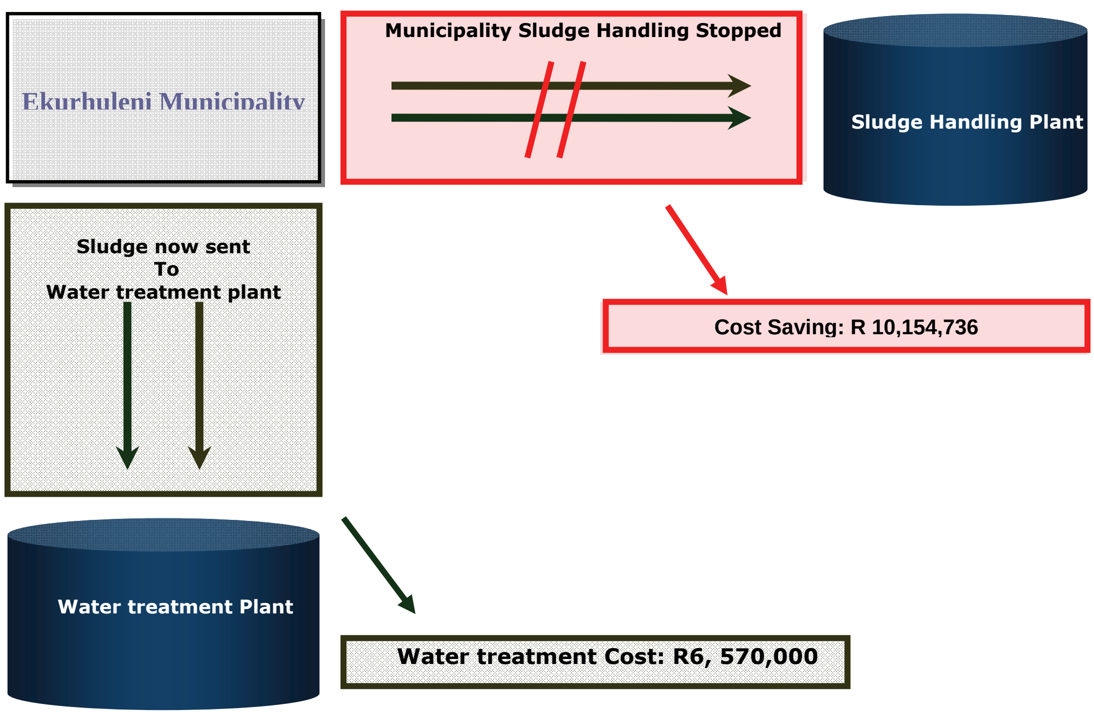


Figure 14: Transfer of sewage sludge from municipality to water treatment process

Before the water treatment plant was built, the municipality would handle sludge volumes of up to 26 172 dry tons per annum at a cost of R10, 15,736 per year. All this sludge is now being transferred to the water treatment plant for use in the BioSure process. The water treatment plant handles at least 10 ML of water per day, treating the water at a cost of R6, 570, 000 per year. This treatment in itself represents a saving compared to alternative treatment processes.

Benefits of this arrangement

- Water is purified and released into the neighbouring river
- Transfer of sludge handling by municipality to water treatment plant.
- The water treatment plant assists municipalities in disposing sewage sludge in an environmentally friendly and cheaper way
- Municipalities make a significant cost saving as they no longer incur costs involved in the disposal of sewage sludge.
- New jobs are created as personnel are required to run the water treatment plant
- New employment ultimately contributes to economic growth of the country

Job Creation

Twenty one jobs were also created following commissioning of the water treatment plant. The personnel employed include in-service trainees, machinery operators and one plant manager. Total annual salaries of R1 320 000 are paid out to this new labor which is a significant benefit to society especially the newly employed workforce.

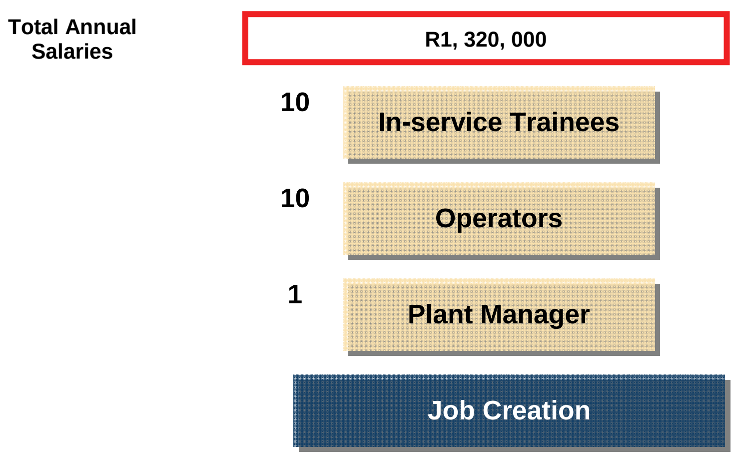


Figure 15: Job creation from commissioning of water treatment

Sale of industrial materials

Through research funded by the WRC water treatment companies have worked on water treatment projects that produce valuable by-products. These by-products can be used in other applications, processes or can even be sold in the industrial market.

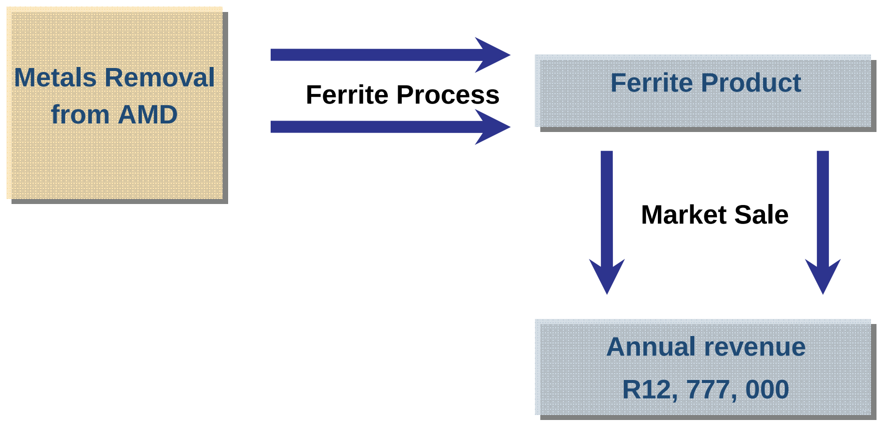


Figure 16: Metal removals process from AMD

An example of such a process is the ferrite process for metals removal from acid mine drainage. This approach involves the controlled oxidation of ferrous containing AMD water at ambient temperatures in the presence of magnetite seed

The resulting oxidation product is the ferrite magnetite which has the capacity for non-ferrous metal removal by cation substitution. The ferrite produced in this process can be sold in the industrial market for at least R350 per ton.

Sustainable Mine closure

The majority of applications put forward by mines for closure are usually turned down for technical and social reasons. The WRC thus identified a need to undertake research into the issue of mine closure planning from a water management perspective in the South African gold mining industry. Some of the reasons for closure denials are that the mining companies seeking closure might fail to meet the surface rehabilitation measures set out by government.

Another reason is that the water quality objectives will not have been set out and agreed upon from the onset thus DWAF will not have a framework to manage an ongoing impact on mines post closure.

Current and potential benefit of regional closure strategy emanating from WRC research.

- Understand the long term risks associated with post closure
- Understand the long term risks associated with post closure seepage from waste residue deposits
- Identify proactive management measures that can be implemented to minimize long term risks associated with decant from mines.
- Identify proactive management measures that can be implemented to minimize the long term risks with seepage from waste residue dumps
- Develop appropriate procedures to ensure that effective closure planning occurs timeously and on an integrated and regional basis.

Conclusion

Application of WRC research by industry has had significant current and potential benefits to society and the South African economy as a whole. Use of their research on water balance models, water treatment technologies and environmental rehabilitation has resulted in environmentally friendly and economically sustainable revenue generating projects such as water treatment plants. The economy has also benefited indirectly from WRC research that has filtered into industry applications such as metals removal processes thus producing by-products such as gypsum and ferrite that can be sold. Significant cost saving benefits have also been derived from projects funded by the WRC on new technologies thus reducing operating costs for organisations such as municipalities. All of these aspects have been to the benefit of society and ultimately to the South African economy as a whole

3.3.3 Case studies

Case Study I: Mine Water Irrigation – Smith Bros Farm

Commercial crop production was conducted on Smith Bros farm by Mr Niel Smith. The mine water used for irrigation of crops on this farm was taken from Kleinkopje colliery. It was pumped from underground as well as from an opencast pit. The Kleinkopje colliery (Witbank, Mpumalanga) currently has some $12 * 10^6$ of water stored underground, and it is estimated from pumping and water level data that the daily water make is in order of 14 ML d^{-1}. This is sufficient to sustain an irrigated area of up to 700 hectares. The crop planting on this farm was conducted on both virgin land and rehabilitated land using three different irrigation management practices as part of a commercial scale field experiment. The practices used were leaching fraction, irrigation up to field capacity and deficit irrigation. The crops production produced very good yields which were subsequently sold at a profit on the market.

Case Study II: Emalahleni water treatment project

The Emalahleni reclamation project was a joint venture between two mining companies in South Africa. Keyplan was awarded the turnkey contract to design, construct and commission the 25 ML a day plant to treat acidic, saline mine water originating from the Witbank coal mining region to a high quality potable water standard. The plant established at a cost of R300 million, treats polluted mine water from underground workings to deliver potable and processed water to the Emalahleni municipality and the surrounding mines.

The project involves a high recovery precipitation reverse-osmosis (HiPRO) process for the treatment of acid mine drainage. It transforms water with a high acidity and sulphate concentration into superior quality drinking water. The project, commissioned in 2007, desalinates rising underground water from 3 collieries as well as a defunct south Witbank mine. It also prevents polluted mine water from decanting into the environment. The plant currently produces over 25 ML of potable quality water a day on average, with a 99% water recovery.

3.4 Environmental Impacts

3.4.1 Introduction

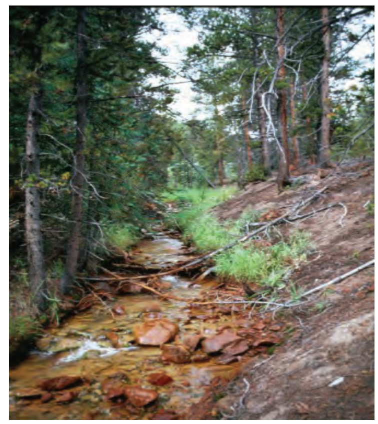
Research studies into mine water management that were carried out by the WRC were aimed at trying to address the problems that are presented by uncontrolled discharge of mine water. The discharged mine water is commonly known as acid mine drainage (AMD) or acid rock drainage (ARD) and is a major environmental problem related to mining in many parts of the world. There is a wide acceptance that AMD is responsible for costly environmental and socio-economic impacts.

AMD has numerous environmental impacts that are very costly to reverse. This phenomenon is characterised by low pH (high acidity), high salinity levels, elevated concentrations of sulphate, iron, aluminium and manganese, raised toxic heavy metals such as cadium, cobalt, copper, molybdenum and zinc. AMD associated with gold mining activities often contain radionuclides. Most of these metals and radionuclides are not only associated with surface water pollution, but also responsible for the degradation of soil quality, aquatic habitats and for allowing heavy metals to seep into the environment.

Surface sources of AMD that present the greatest threat are coal discard dumps and slurry dams, gold tailings/slimes dams and waste rock dumps, and uranium slimes dams. Subsurface impacts are generally associated with water ingress (flooding) into underground mine workings, with the attendant threat of polluting underground water sources. This normally happens in the post mining phase, providing a source of acid mine water for potential migration into the groundwater environment during re-establishment of water tables.

In South Africa, large quantities of AMD are currently decanting onto the surface on the West Rand and far West Rand area in the Gauteng Province. This is having significant adverse effects on the ecosystems within this area.

Acid mine water started to decant from defunct flooded mines underground workings on the West Rand in August 2002.



The AMD has found its way into a natural water course that flows northwards through the Krugersdorp Game Reserve (KGR) towards the Cradle of Humankind World Heritage Site.

This has caused some severe damages to the ecosystem and has killed a lot of wildlife in the KGR.

WRC research Impact

The WRC's research into mine water management will help alleviate some of the negative environmental impacts that have resulted from decades of mining activities. Pioneering research by Scott on the impacts of mining concluded that pumping would lead to the filling of what he called mining aquifers and eventual decant of AMD on the surface. He also identified prevention of water ingress as a major component to reduce the eventual quantity of AMD decant. Furthermore, the WRC researched the treatment of AMD through active and passive means in order to reduce the impact of AMD itself.

Some of WRC's research that was aimed at raising awareness on the negative impacts of AMD is shown in the table below;

Table 6: WRC reports on AMD

WRC's research aimed raising awareness	
136/1/89	Research on the contribution of mine dumps to the mineral pollution load in the Vaal Barrage
486/1/95	Flooding of central and East Rand gold mines: An investigation into controls over the inflow rate water quality and the predicted impacts of flooded mines
523/1/96	A manual to assess and manage the impact of gold mining operations on the surface water environment
291/1/98	Groundwater quality deterioration in the Olifants River Catchment above the Loskop Dam with specialised investigations in the Witbank Dam sub-catchment
800/1/00	An economic and technical evaluation of regional treatment options for point source gold mine effluents entering the Vaal Barrage Catchment

The WRC's research entitled **'Rehabilitation of Contaminated Gold Tailings Dam Footprints,** which was published in 2003, is one of many research projects that will contribute to the rehabilitation and remediation of the West Rand mining area. The main objectives of this study were to;

- Evaluate and define the existing state of knowledge with regard to reclamation and rehabilitation methods and their water quality impacts.
- Provide site-specific assessments of the potential of contaminants released from gold mine tailings facilities and soil underlying reclaimed tailings facilities to pollute the aquatic pathways (surface and groundwater), with regards to heavy metals, salts and radio-nuclides.
- Develop rehabilitation management strategies based on site-specific conditions to minimise the environmental impact on the aquatic pathway.
- Provide guidance for future land use after complete reclamation.

Implementation of WRC's research aimed at preventing or minimising the negative effects of mining activities and supplemented by research to rehabilitate damaged ecosystems will result in benefits that include; reduced degradation of soil quality; reduced surface water pollution; and limited groundwater pollution.

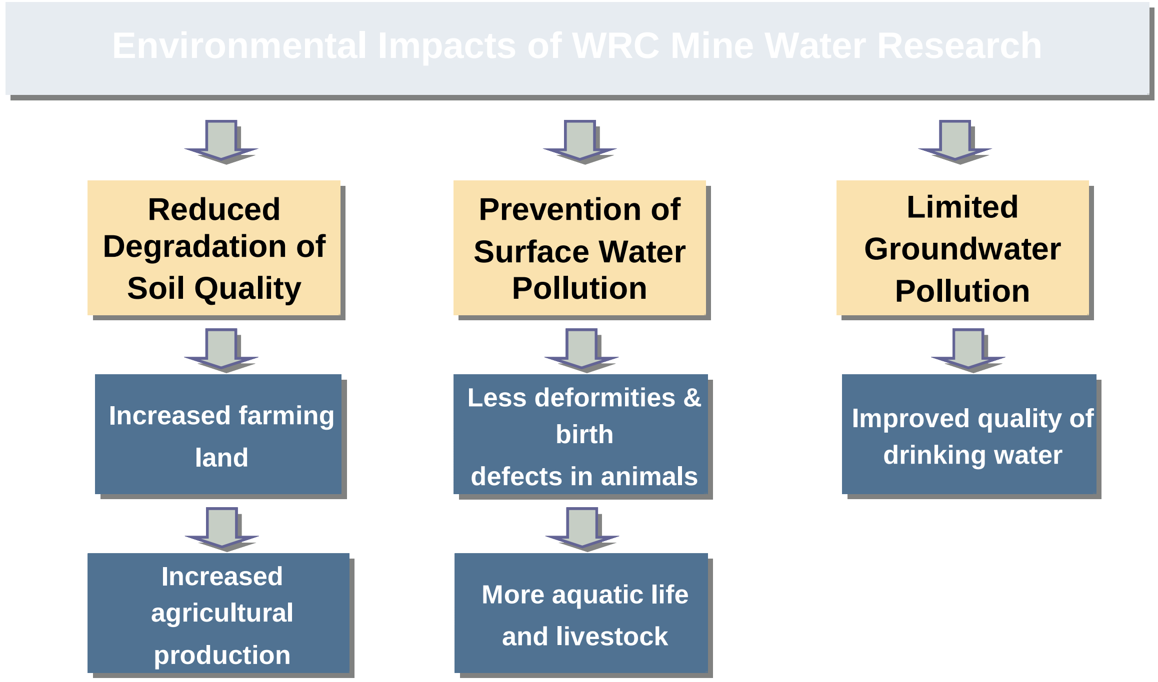


Figure 17: Environmental Impacts of mine water in South Africa

Table 7: Environmental benefits of WRC's mine water research in South Africa

Reduced degradation of soil quality		Effective mine water management throughout the mine's lifetime helps reduce environmental impacts such as farmland contamination. Decanted water with toxic metals and acids can pollute farmland thereby compromising the continuity of mining operations, either in part or whole. Farming communities stand to lose their source of livelihood when their land gets polluted by mine water.
Prevention of surface water contamination		Surface water contamination through mining activities results in salination of water sources. This is considered to be a risk to the sustainable use of water resources and could pose a risk to the ecology of the system. Contamination of surface water sources poses a serious threat to both aquatic and wildlife. Deformities and birth defects have occurred in wildlife exposed to contaminated surface water.

Limited groundwater contamination		One of the most serious consequences of not treating mine water is the resultant contamination of ground water resources. In the mining district of Johannesburg, polluted groundwater is discharging into streams in the area and contributes up to 20% of the stream flow, causing an increase in the acidity of the stream water. The effect of this contamination can persist for more than 10km beyond the source. Effective mine water management, with reference to WRC's research, has resulted in reduced groundwater contamination.

3.4.2 Quantification of Impacts

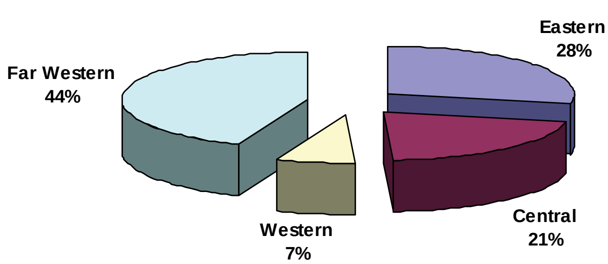
Land clean up costs

The treatment of AMD is currently underway throughout South Africa's major mining areas. The first phase of clean up will cost R 410,400,000. Approximately 44 percent of all clean up costs will be attributed to the far West Rand area.

Table 8: Breakdown of costs to treat AMD during the first phase by region

Basin	Cost per Day	Cost per Month	Cost per Year
Eastern	R 320,000	R 9,600,000	R 115,200,000
Central	R 240,000	R 7,200,000	R 86,400,000
Western	R 80,000	R 2,400,000	R 28,800,000
Far Western	R 500,000	R 15,000,000	R 180,000,000
Total	**R 1,140,000**	**R 34,200,000**	**R 410,400,000**

The Eastern and Central Basins are expected to start experiencing high decanting rates and these should result in combined clean up costs of approximately R 201,600, 000.



Most mine water decanting has been occurring in the far Western Basin and this region is expected to incur most of the clean up costs.

Figure 18: Regional breakdown of costs to treat AMD during the first phase

Mining companies are primarily liable for the AMD within the West Rand Basin. The state is also responsible for some of the abandoned mines in this area. These are mines that were closed prior to the passage of the Mines and Works Act (Act 27 of 1956).

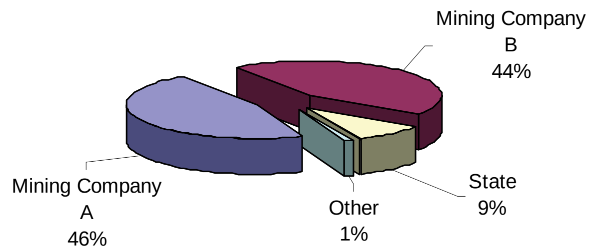


Figure 19: Percentage breakdown of AMD liabilities in the West Rand Basin

The ramifications of AMD for the West Rand region are significant. Most of the focus is centered on the Cradle of Humankind World Heritage Site. Downstream landowners and agricultural activities are of equal importance. These are largely or wholly dependent on groundwater for potable and economic use.

Surface water clean-up costs

The WRC has worked extensively on various wastewater and waste management projects with different stakeholders. It has done extensive research on the treatment of Acid Mine Drainage in an effort to reduce remediation costs. It is estimated that approximately 300 abandoned collieries are producing AMD. An estimated 3 billion Rands is required from public funds to ameliorate this since ownership of these collieries cannot be established.

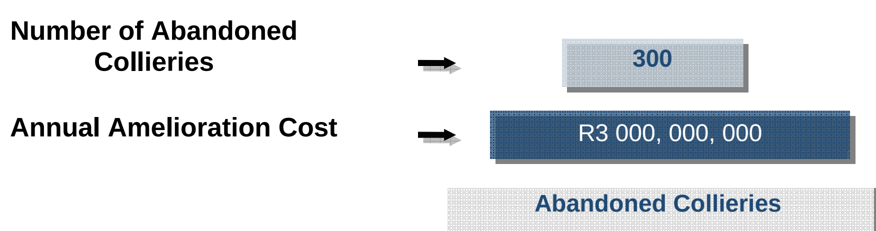


Figure 20: Amelioration costs of abandoned collieries

The majority of old collieries are burning underground hence large tracts of land are being destroyed and arable land is collapsing. A high density sludge liming plant was thus set up at Brugspruit to treat polluted water from collieries because it was decanting into a stream which was a direct water source for nearby communities living on the banks of the river. The capital costs for this project were R10, 000, 000 per ML, per day while the operating costs were in the range of R1.58 per cubic meter of water treated using lime alone.

Table 9: Capital costs for the development of the high density sludge liming plant

High Density Sludge Liming Plant		
	Unit	**Cost**
Capital Costs	Per ML/Day	R10,000 000
Operating Costs	Per cubic meter	R1.58

Losses and damages incurred on wildlife and the ecosystem in the Krugersdorp Game Reserve as a result of AMD in Tweelopiespruit

The Tweelopiespruit is considered to be a Class V River with a 'Very High Acute Hazard'. This river flows through Krugersdorp Game Reserve (KGR) and recently recorded a drastic drop in macro invertebrates with organisms considered to be very tolerant to pollution being the only ones remaining. Virtually, all aquatic life has died.

Damages experienced at the KGR are valued in terms of lack of breeding amongst most animals within the Reserve. These have taken the form of miscarriages, deformities and birth defects which now appear in increasing numbers in the valley.

Losses and damages incurred that are directly linked to the water pollution in the Tweelopiespruit can be classified under four broad headings namely; mortalities, lack of breeding, damages to gardens and damages to equipment.

Table 10: Losses and damages incurred in the Krugersdorp Game Reserve to date

Damages	Rand Value
Animal Mortalities	**289,275**
Lack of Breeding	**804,874**
Damages to Gardens	**50,000**
Damages to Equipment	**24,000**
Total	**1,168,149**

Conclusion

Use of WRC research to ameliorate the environmental impacts that have been qualified and quantified above could result in a significant reduction of rehabilitation costs and improvements in the overall state of the environment. Reduced degradation of soil quality could positively impact the size of arable farming land as well as increase agricultural production. The prevention of surface water pollution could also result in less deformities and birth defects in animals. All these secondary benefits that have been identified could be attained through the effective use of WRC research by industry

3.4.3 Case Study

Case Study 1: Krugersdorp Game Reserve surface water contamination

The Krugersdorp Game Reserve (KGR) has been experiencing excessive water pollution due to uncontrolled discharge of contaminated water (or decant) from some abandoned mines within its catchments area. This has resulted in a drastic increase in the animal mortality of the reserve. Despite close attention to such problems, little has been done in trying to find lasting solutions. The animal health problem manifested soon after contact with polluted water.

Soon after decant began, 2 mining companies up water treatment plants near Krugersdorp. Despite neutralising the acidity, the treated water still has higher than normal metal concentration, it flows into the Tweelopiespruit just before the KGR through a hole in the ground called Buks se Gat. In the reserve, the water has filled a once dry dam. Though treated, the water is still murky brown and turns plant life orange, a result of high iron and manganese levels.

It was demonstrated that the pollution emanating from the mines via the Tweelopiespruit and the mechanisms involved caused the ground water contamination. Aquatic life has died and several animal mortalities have been linked to the mining pollution in the Tweelopiespruit.

African Bush Adventures, which manages the reserve, recently wrote to the Department of Water Affairs detailing the death of aquatic life and buffalo, as well as aborted babies of two rhinos. It attributes these and other incidents to the quality of water.

3.5 Social Impacts

3.5.1 Introduction

Contaminated mine water has various direct and indirect impacts on society. These impacts are closely related to environmental impacts and land contamination that renders any farming activities unsuitable.

Pollution of farming land by decanted mine water can result in toxic elements leaching into the soil, sometimes altering its chemical balance. This has a direct impact on surrounding communities as they are forced to relocate to alternative farming areas. This comes with a monetary cost of relocating and the inconvenience endured when relocating. Relocation also results in sentimental damages as most farming land is passed-on from one generation to the other.

Mine water has various effects on different animals. Animals react slightly differently to the use of contaminated water and feed that is produced under these circumstances. However, according to a report compiled by a veterinarian Dr. Jerry Retief, there are certain symptoms that correspond with virtually all affected animals and these include;

- Miscarriages which have occurred in sheep, goats, cattle and swine.
- Deformities and birth defects that affect the joints of affected animals.
- Stiff gait occurs frequently with swollen joints.
- Diarrhoea

The WRC's research is expected to play an important role in mitigating the negative social impacts that mine water has had in South Africa. There are some cases were farmland has been lost and peoples' livelihoods have been compromised as a result of mine water contamination.

WRC research on the **' Rehabilitation of Contaminated Gold Tailings Dam Footprints'** will be significant in addressing the damages that have been caused as a result of mining operations in this area.

This research provides guidance for future land use after complete reclamation. The extent and type of contamination in the unsaturated zone determines the type and extent of rehabilitation that would be required for safe future land use and the prevention of groundwater contamination.

The utilisation of WRC's research into mine water presents tangible benefits to society. Some of these benefits are highlighted below.

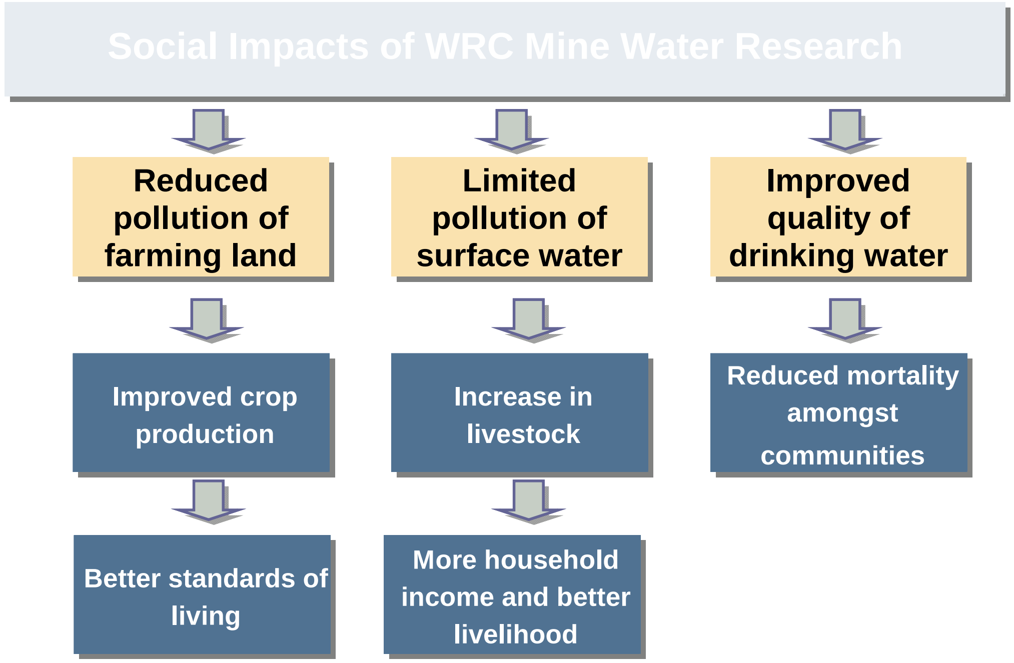


Figure 21: Social Impacts of WRC mine water research in South Africa

Table 11: Social benefits of WRC's mine water research in South Africa

Reduced pollution of farming land		The application of WRC mine water research should help reduce farmland pollution and improve on crop production, thereby helping improve society's standard of living. Well balanced chemical content in farming land produces higher yields.
Limited pollution of surface water		Effective treatment of mine water limits the pollution of surface water sources. Pollution of surrounding surface water sources could kill any livestock that depends on such sources, which would mean a loss of livelihood for the dependent communities.
Improved quality of drinking water		WRC's mine water research has resulted in advanced technological development to purify to water. Mine water treated using such technologies is of a high quality and more suitable for industrial processes.

Conclusion

Some significant improvement in the standard of living for society could be realised through the utilisation of WRC research. Particular focus needs to be placed on limited surface water pollution and reduced pollution of farmland. The major benefits of these impacts would be improved agricultural production and reduced mortalities amongst society.

3.5.2 Case Studies

Case Study I: Gold mining company's water treatment plant pollution

Farmer Dawie Lotter conducts his farming activities just outside Krugersdorp and is adjacent to a mine water treatment plant. This plant was set up to deal with acid mine drainage. However his land cannot be farmed and has been rendered useless as a result of decanted water flooding his land. This has brought in toxic metals and acid that have resulted in sand turning orange and in the worst affected areas, even grass will not grow.

Farmer Dawie Lotter

> **"Yes, Dawie, we'll sort it out for you. Don't worry. Just give us time, they said. Now my time is also up and nothing has been done."… "You can see what the mines have done to my property. Let them buy me out" – Farmer Dawie Lotter.**

The Dawie Lotter family has been owners of their land for over 40 years and they have been farming potatoes and pumpkins. Farming used to very profitable until their land became contaminated by acid mine drainage that has been a result of mining activities within the area. A few years ago farmer Lotter bought 15 imported show horses which he reared and trained on the land. However within two years, eight of his horses had died and the rest were sick, hence he was forced to sell them.

More recently Dawie's brother tried to make a living rearing cattle and sheep off the land. However within a few months, half of his flock of 60 sheep died. He decided to sell the rest of his flock soon after this incident. With no use for the land, the Lotters have given up trying to make a living on it and have reached an agreement with the mining company to buy his farm out.

Case Study II: Fochville water pollution

Since 1998 the farmers within the Fochville area have noticed that the quantity and quality of their crops, produce and livestock production have deteriorated. There is a strong speculation that this deterioration is related to the significant salt load and heavy metals from mine effluent into the Leeuwspruit Catchment. A farmer within this area, Mr Pieter Rheeder, has been compelled to terminate his farming activities as a direct consequence of the poor quality of his groundwater. The river bed and flood plains of the Leeuwspruit are visibly contaminated and the pollution from the mine effluent has had a significant detrimental impact upon the aquatic biota with a visible absence of freshwater vertebrates, invertebrates and plants. The borehole water, the only available water source of Mr Pieter Rheeder is no longer fit for human and animal consumption.

3.6 Health Impacts

3.6.1 Introduction

Contaminated mine water can have adverse health impacts when consumed by human beings. These include illnesses such as cancer, which result from ingestion of unsafe levels of radionuclides.

Much mine water pollution is currently taking place within the West Rand Basin and communities living within surrounding areas are the most exposed to the risk posed by decanted mine water drainage. Based on possible water borne pollution and water toxicity, the communities at risk are situated within the Tweelopiespruit Catchment, including the dolomitic aquifers and in particular the Zwartkrans dolomitic aquifer. These communities are summarised in the table below.

Table 12: Communities exposed to risk in the West Rand Basin

Wards	Area	Size (ha)	Number of People
27	KGR; Oaktree;Oatlands; Waterval;portion of Protea Ridge Agricultural Holdings	3,755	7,000
30	Tarlton (including Marabeth, Beckedan, Helderblom, Sterkfontein & Eldorado Agricultural Small Holdings)	13,371	14,931
Total		**17,126**	**21,931**

Source: MCLM GIS Database

Approximately 2,654 hectares of land is under irrigation using borehole water: 70.3 Ml/day is abstracted from the aquifer within the Zwartkrans compartment for irrigation, which includes small areas within the smallholding areas of Beckendan, Eljeesee, Marabeth, Helderblom, Vlakdrift, Oaktree and Eldorado.

Nearly 458 hectares of land is under irrigation using river water. The total amount is calculated at 8.93 Ml/day. The domestic use of the water within the Zwartkrans compartment amounts to 3.45 Ml/day. The 3.45 Ml/day are used by 11 491 people living on dolomite using 250l/person/day groundwater.

Mine water often causes sicknesses that could result in death or absenteeism from work. This results in loss of income to the family that was depended on the deceased's income. Absenteeism from work results in a loss of production to the employer.

3.6.2 Case Study

Case Study 1: Wonderfontein Catchment area

The Wonderfonteinspruit Catchment area is situated between Johannesburg and Potchefstroom and covers many of the richest gold mines in the world. Gold ore from these mines contains uranium which is a by-product of gold and it is estimated that the six billion tons of tailings (mine dumps) contain about 600 000 tons of uranium exposed to the biosphere. In addition uranium tailings also contain cadmium and arsenic, both of which are categorized as human carcinogens.

Services of Cancer Association of South Africa (CANSA) are available to residents in Randfontein and Carletonville. Residential areas in close proximity to mining operations as well as CANSA have been approached by local non-governmental organisations to investigate the possible cancer risk in this particular environment.

During 2008 three employees of CANSA, while visiting a specific tailing area close to Carletonville and seated on the back of an open vehicle close to the end of a convoy of vehicles, were exposed to dust caused by the vehicles and became ill with the following symptoms; unusual headaches, myalgia, loss of appetite, eye irritation, sore throats, nausea, severe diarrhea and skin rashes. In order to understand this unexpected phenomenon, soil samples were collected across a transect including the exact locality where the dust was encountered.

To obtain objective information on the chemical and physical properties of tailings dust that may had caused CANSA employees to become ill, soil samples were analysed for water soluble cations and anions, average diameter of particles in dust and Geiger Counter readings of combined alpha, beta and gamma radioactivity.

The pale yellow powder considered to be the most likely source of contamination because of exact locality had the following important characteristics; particles with an average diameter of about 50 micro-meters; radioactivity of 869 counts per second (Control = 0.5 cps), water soluble arsenic of 109 mg/kg.

It is postulated that the CANSA employees became ill due to exposure and possible inhalation of a specific deposit of tailings dust that was both radioactive and contained arsenic. The particles containing more than one type of carcinogen (radioactivity and arsenic) may have enhanced carcinogenicity. It is considered important to determine to what extent tailings dust with the characteristics reported here has contaminated residential areas in Carletonville. It was then recommended that all visitors to areas contaminated with tailings dust should wear face masks.

4. Conclusion

Since its establishment in 1971, the WRC has been conducting research on mine water management. It is seen as a dynamic hub for water-centered knowledge, innovation, and intellectual capital. The WRC has provided leadership for research and development through the support of knowledge creation, transfer and application. It has engaged various industry participants in solving water related problems which are critical to South Africa's sustainable development and economic growth.

In order to retain its standing with various industry participants the WRC has embarked on this study with the aim to quantify and qualify the current and potential impact that research conducted by the WRC, in the field of mine water, has had on South African society with particular emphasis on the variables: **economic** impacts, **environmenta**l impacts, **social** impacts & **health** impacts.

A summary of the impacts identified during this project are outlined below:

IMPACT AREA		IMPACT
ECONOMIC		
	**Revenue Generation**	Mine water irrigation
		Crop Production
		Fuel & Power
	Industrial Materials	Building Materials
		Mining Products
		Fertilizers
	Cost Saving	New Technologies
		Sustainable mine closure
	Water Treatment	Potable Water

With regards to economic impacts, primary and secondary benefits from the application of WRC research by industry were identified. Revenue generating projects such as crop production using mine water for irrigation and generation of fuel and power using mine water were analysed in detail. Cost saving benefits derived from new technologies and implementation of sustainable mine closure procedures were also identified as significant benefits to society as well as provision of clean piped water through establishment of water treatment plants.

IMPACT AREA		IMPACT
ENVIRONMENTAL		
	**Reduced degradation of soil quality**	Increased farming land
		Increased agricultural production
	Prevention of surface water pollution	Less deformities & birth defects in animals
		Reduced loss of aquatic life and livestock
	Limited ground water pollution	Improved quality of drinking water

The environmental impacts that were identified referred to the impact of mine water on the environment and the subsequent benefits of utilising WRC research to ameliorate these impacts. Key impacts that were identified were the reduced degradation of soil quality leading to increased farming land, limited ground water pollution with the benefit of improved quality of drinking water and the prevention of surface water pollution which ultimately reduces loss of aquatic life and livestock.

IMPACT AREA		IMPACT
SOCIAL		
	**Reduced pollution of farmland**	Improved agricultural production
		Improved standards of living
	Limited pollution of surface water	Increase in livestock
		More household income and livelihood
	Improved quality of drinking water	Less incidences of waterborne diseases
		Reduction in mortality amongst communities
	Job Creation	Improved standard of living

Social impacts focused on the direct and indirect impact of WRC research and associated environmental issues on society. Both primary and secondary benefits to society were analysed in detail and key impacts identified. Impacts such as improved standard of living were quantified through the number of jobs created and the subsequent salaries paid out as well as the provision of piped water for the local community. Improved quality of drinking water was also identified with the benefit of fewer incidences of waterborne diseases. Other social impacts highlighted were reduced pollution of farmland and the subsequent increase in agricultural production as well as limited pollution of surface water.

IMPACT AREA		IMPACT
HEALTH		
	**Prevention of sickness**	Reduced incidences of loss of life
		Substantial income to the immediate family
		Less cases of work absenteeism
		Improved income for the company

Health impacts focused mainly on those aspects of mine water management that affect the health of the community. An impact assessment of WRC research on these health issues was then conducted and the benefits attributed to society detailed. The main secondary impact identified was the prevention of sickness ultimately resulting in benefits such as reduced cases or work absenteeism and reduced incidences of loss of life.

All the impacts identified during this project clearly reflect that WRC research on mine water management has had a positive impact across economic, environmental, social and health aspects of South African society. Consistent application of WRC research by industry could also produce the potential benefits identified, thereby benefiting society and ultimately South Africa as whole.

Appendix 1

Year	Project #	Project Name	Project Aim
1990	1	The water requirements and pollution potential of south African gold and uranium mines	The aim of this research study was to outline the magnitude and consequences of pollution by mines and related activities. This led to the development of ice for mine cooling, the production of slurry ice from high TDS mine water for simultaneous cooling and desalination and the introduction of energy saving hydro-powered drills and hydrolift mine cooling systems
1995	2	A manual on mine water treatment & management practices in south Africa	Technically and economically define viable procedures for ameliorating the impact of gold mining operations on the surface water environment.
1996	3	A manual to assess and manage the impact of gold mining operations on the surface water environment	Define the current water management and treatment practices in the south African gold mining and coal industries
1998	4	information transfer, extraction and management systems	Development of computerised information transfer, extraction and management system for mine water quality management, treatment and research.
1999	5	The performance of natural soil covers in rehabilitating opencast mines and waste dumps in south Africa	Understand the behaviour and to assess the effectiveness of soil covers designed to control the rate of leaching of pollutants from discard dumps and waste piles
2000	6	An economic and technical evaluation of regional treatment options for point source gold mine effluents entering the Vaal barrage catchments	The study was aimed at developing strategies to cost effectively manage/treat point source mining effluents
2001	7	A generic water balance for the south African coal mining industry	The aim of the study was to develop an industry wide water balance
	8	Pilot scale development of integrated passive water treatment systems for mine effluent streams	Development of low cost , self sustaining passive water treatment systems to address the problems of acidification and salination at operating defunct and closed mines
	9	An internet service centre on water modelling systems for the mining industry	The study was aimed at developing water modelling systems for the mining industry
2002	10	The influence of irrigation with gypsiferous mine water on soil properties and drainage water	The aim of the study was to ascertain weather gypsiferous mine water can be used on a sustainable basis for irrigation
	11	Quantification of the water balance of selected rehabilitated mine soils under rain fed pastures in Mpumalanga	The aim of the study was quantify water balance and develop models to make long term predictions of water balance
2003	12	Field testing for real-time continuous flow and water quality monitoring instrumentation	The study was aimed at monitoring flow and water quality parameters in open channel flow systems
	13	Guidance for the rehabilitation of contaminated gold tailings dam footprints	The study was aimed at changing the technical approach to evaluating and remediating contaminated land.
	14	Rehabilitation of contaminated gold tailings dam footprints	The aim of the research study was to develop a guideline for the rehabilitation of the footprint of these reclaimed gold mine tailings facilities
	15	A decision support system for the controlled release of saline mine water during flood conditions in the Witbank dam catchments	The study was aimed at establishing a predictive tool to analyse and develop a better understanding of the controlled release of saline mine water
	16	On-site and laboratory investigations of spoil in opencast collieries and the development of acid-base accounting procedures	Quantify the potential and magnitude of acid mine drainage under south African open cast mining conditions
	17	Acid-base: Accounting techniques and evaluation (ABATE) : Recommended methods for conducting and interpreting analytical geochemical assessments at opencast collieries in south Africa	Quantify the potential and magnitude of acid mine drainage under south African open cast mining conditions
2004	18	A novel one-step ambient temperature ferrite process for the removal of metals from acid mine drainage	Removal of dissolved metals from acid mine drainage
	19	The effect of the chemical properties of tailings and water application on the establishment of a vegetative cover on gold tailings dams	Determination of which commonly used rehabilitation methods for gold tailings produced the most suitable vegetation cover at the end of the rehabilitation period
	20	water related impacts of small scale mining	Development of regulatory and administrative procedures, reserve determination, business plans and mining methods for small scale farmers

	21	The evaluation of soil covers used in the rehabilitation of coal mines	Understand factors that result in generation of leachate then Calibrate existing flow models to optimise cover design, given the soils available for cover.
	22	Electrochemical treatment for the removal of sulphates from acid mine drainage	Assess and demonstrate the ability of the electrochemical process as a process for the removal of sulphate and phosphate pollutants from typical effluents.
	23	Long term impact of inter-mine flow from collieries in the Mpumalanga coalfields	Identification of critical area's were inter-mine flow is likely and quantification of flows through field measurement
	24	Neutralization of acid mine water and sludge disposal	Identify the most cost effective neutralization process for acid mine water
2005	*25*	*The development of appropriate procedures towards and after closure of underground gold mines from a water management perspective*	*Regional Mine Closure Strategy*
	26	The potential of permeable reactive barrier(prb) technology as a remediation tool for contaminated mine groundwater : literature review; preliminary laboratory analysis and assessment	Assess the application potential permeable reactive barriers (PBRs) under local conditions
	27	Biosorption of heavy metals from aqueous solutions	Identification of suitable biosorbent and characterization of the sorbent and biosorption mechanisms
	28	Utilization of fly ash for acid mine drainage remediation	Utilization of fly ash for acid mine drainage
	29	Implementing the degrading packed bed reactor technology and verifying the long-term performance of passive treatment plants at Vryheid coronation colliery	Implementing the degrading packed bed reactor technology and verifying the long term performance of passive treatment plants
	30	An investigation into the depth and rate of weathering on gold tailings dam surfaces as key information for long term and risk assessments	The aim of this research study was to try and establish the relationship between the depth and rate of weathering and the potential mass of acidity at gold FRDs through empirical analysis.
2006	31	An assessment of sources, pathways, mechanisms and risks of current and potential future pollution of water and sediments in gold-mining areas of the Wonderfonteinspruit catchments	The objective of the study was undertake a risk assessment of metals and metalloids in the Wonderfonteinspruit catchment and then provided critical information to stakeholders in the catchment.
	32	An evaluation of the performance and effectiveness of improved soil cover designs to limit through-flow of water and ingress of air	Understand the performance of soil covers used In the rehabilitation of coal discard dumps, open cast and coal mines
	33	A quantitative evaluation of the modal distribution of minerals in coal deposits in the highveld area and the associated impact on the generation of acid and neutral mine drainage	The study aimed at gaining a quantitative understanding of the mineralogy of the coal measures in the Highveld coal fields of South Africa.
	34	Stability and neutralization capacity of potential mine backfill material formed by neutralization of fly ash and acid mine drainage	The aim of the research study was to determine process parameters for acid mine drainage (AMD) neutralisation and the extent of removal of toxic heavy metals from acid mine drainage as well as long-term stability of bulk solid residues.
2007	35	Toxic element removal from water using zeolite absorbents made from solid waste residues	The primary aim of this research project was to develop adsorbents for toxic element removal and more specifically, develop a synthesis method for zeolite production from the solid waste residues remaining after the neutralisation of acid mine drainage (AMD) with Fly Ash (FA).
	36	Predicting the environmental impact and sustainability of irrigation with coal mine water	To determine the impact of irrigation with several mine water qualities/soil combinations on soil conditions and groundwater quality.
	37	Investigation of water decant from the underground collieries in Mpumalanga, with special emphasis on predictive tools and long-term water quality management	Investigate and describe the status quo in terms of mining methods, scheduling geology, geohydrology, hydrochemistry, water and salt balances at six underground collieries that are in the process of decanting or where decanting is imminent.
	38	The microbiology of fly ash-acid mine drainage neutralization systems	To identify the microbial associated with the input and the output phases of Fly Ash / AMD remediation systems.
2008	39	Determination of the impact of coal mine water irrigation on groundwater resources	The determination of hydraulic interaction of irrigated mine water with underlying aquifers