WATER INNOVATIONS MARKET DEMAND ANALYSIS IN THE MINING SECTOR

Caroline Wadsworth and Jo Burgess

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Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

There is an urgent need to implement water innovations in the mining sector in South Africa and there is a strong national capacity for research and development providing such technologies. However, the newly developed technologies do not enter the market quickly or easily, despite government ambition for policy and regulatory frameworks to promote these advancements. Knowledge gaps exist regarding the extent of uptake and successful deployment of water innovations in the South African mining sector, as well as a clear differentiation of the sub-markets within mining sector. This project set out to identify and assess the drivers, barriers, enablers, and projected demand for water innovations in the mining sector in South Africa.

The aim of the project was to improve the understanding of the mining industry and government entities as consumers of water innovations and estimate potential size of the mining water innovations market. To serve this aim, there were six objectives:

1. Develop methodology to assess and determine the size and potential of a mining water innovations market;
2. Provide a situational analysis, unpack the characteristics of the market, and provide a demand forecast;
3. Undertake a market segmentation analysis, providing a sub-market view for potential uptake;
4. Outline key developments required to improve market structure;
5. Recommend industrial development, process, technological and implementation strategies to be pursued that acknowledges existing regulatory frameworks; and
6. Provide recommendations for future research, policy, and practice.

Using a phased approach, the project team created an overview of the organisation and process flow of innovation scouting, testing, adaptation and roll-out in the mining industry and assessed the regulatory and research landscape. Second, the team undertook a market insights study to drill down into the gaps in innovation trends and map them against the technology needs / demands articulated by technology users and sector regulators. This insights study provided recommendations into market opportunities and supported justifying investment into further business development. The third and final phase of the project entailed a critical analysis that provided a quantified market forecast and further recommendations for future research, policy adjustment, and translation of best practice to common practice.

In order to assess the market readiness level (MRL) of water innovations for the mining sector, we used a combined MRL to measure the market pull against the technology push associated with technology readiness levels (TRLs). The MRL is therefore strongly based on demand with the additional consideration that whichever solution is chosen, it has to fit in to the mining industry environment. The TRLs used here are the standard TRLs used by the WRC and national government, ranging from 1 (principles observed and reported) to 9 (commercial trials).

The key results are the opportunities map and decision matrix shown on the following page.

Desalination, active mining-impacted water treatment, passive acid mine and rock drainage treatment, tailings management, safe site closure, monitoring and above all digital solutions provide clear immediate opportunities that could be implemented by mining companies and the public sector.

However, while there is an urgent and important need for water innovations on more than ten thousand sites, the size of the current market is closer to five technology end-users. The market is severely constrained by the conservatism of the mining sector, the lack of regulation enforcement, and a desperate shortage of funding and a clear mandate for the sites in the hands of the public sector to take up water innovations. Additionally, the majority of academic research was not focused on the most important problems faced by the private sector.

	New mines	Operational mines	Closed mines	Remining dumps
Desalination for water reuse	TRL 9 MRL 9	Only where there is a poor water balance	Where there is excess water and an offtaker	TRL 9 MRL 9
Active MIW treatment	Any site with excess water	Any site with excess water	Where there is excess water and an offtaker	Any site with excess water
Metals recovery (waste beneficiation)		If metals are present in economic quantities		If metals are present in economic quantities
Reagent recovery (waste beneficiation)	If reagents are present in economic quantities	If reagents are present in economic quantities		
Passive AMD and ARD treatment		In the future; should be planned now	TRL ranges from 2 to 9	TRL ranges from 2 to 9
Tailings management	TRL 9 MRL 6	TRL 9 MRL 6	TRL 9 MRL 6	
Closure and site remediation		In the future; should be planned now	TRL 7-9 MRL 3	TRL 7-9 MRL 7
Digital monitoring & management	TRL 9 but opps for innovation; MRL 9	TRL 9 but opps for innovation; MRL 9	TRL 9 but opps for innovation; MRL 9	TRL 9 but opps for innovation; MRL 9

MIW = mining-impacted water; AMD = acid mine drainage; ARD = acid rock drainage; TRL = technology readiness level; MRL = market readiness level

Key: **Green**: opportunity to be targeted immediately | **Amber**: Possible opportunity under certain conditions

The forecast size of the market, if the recommended policy, practice, and research recommendations are implemented, is predicted to grow over the next five years. Total capital expenditure on water management and treatment in the sector is forecast to increase from R18.2 billion by the end of 2021 to R21.6 billion in 2026, with water supply infrastructure (including desalination of MIW and on-site recycling), mine dewatering, and water and wastewater treatment accounting for 70-71%, 10-11% and 19-20% of expenditure, respectively.

The fastest growing technology area is digitalisation. Spending on online sensors / meters (physical and water quality) takes up the biggest proportion of this market and growth is expected to remain strong. Online sensors and meters are taking the place of lab and field testing. COVID-19 accelerated a pre-existing growth of digitalisation in 2020 / 21 and since online sensors / meters are more efficient than lab / field testing, require lower OpEx, and are more accurate, and investment in digital systems involves CapEx, we predict that mining will not revert to previous monitoring methods after the pandemic. Supply of online instrumentation for remote dewatering and abandoned mines will therefore present increasing opportunities, as will the need for compact low powered sensor systems with the current market of R4.5 billion in 2021 leaping to R8 billion in 2026.

Most of the treatment technologies used in the mining industry are basic. Over half of spending in 2016-2020 was on solids removal with conventional technology. Given the risk aversion of the sector that was evident in this study, we do not predict that innovative treatment technologies will grow their share of the total water technology expenditure unless deep and sweeping regulatory changes are implemented.

The team concluded that considerable institutional reform needs to occur in order to translate the innovation needs into an innovation market. The regulatory bodies do not consistently implement the existing regulations in a way that achieves the desired response from the mining sector to implement new innovations. Reasons for this vary and include the existing complex and unrealistic closure requirements, and a declining sector which is unwilling or unable to respond. The engineering, procurement, and construction contractors and technology developers are frustrated by the mining companies' tendency to return repeatedly to service providers and technologies they are already very familiar with and their reluctance to try anything new, even if it has been demonstrated in similar circumstances on another company's site.

The single most impactful recommended action is to stimulate collaborative water-related applied research for innovations from TRL 5-6 (has been demonstrated in a relevant environment) and upwards. Strong relationships between the technology developers, technology users, and regulators would solve, at least partially, most of the challenges involved in creating a market pull for water innovations in the mining sector.

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Reference Group	Affiliation
Rajiv Paladh	Bosch Capital
Gerhard Fourie	Department of Trade, Industry and Competition
Bashan Govender	Department of Water and Sanitation
Kelley Reynolds-Clausen	Eskom
Stephinah Mudau	Minerals Council of South Africa
Martin Ginster	Sasol Group Services
Muhammed Patel	Trade & Industrial Policy Strategies
Chantal Ramcharan-Kotze	Water Research Commission (Chairperson)

Interviewees (in alphabetical order)	
African Rainbow Minerals	Mine Water Coordinating Body
Alcoa	Mintek
BHP Billiton	Petra Diamonds
Bigen Group	Proxa Water
Black Mountain Mining (Pty) Ltd	Richards Bay Minerals
Council for Geoscience	Rio Tinto
Department of Agriculture, Land Reform & Rural Development	Royal Bafokeng
Department of Mineral Resources & Energy	Sedibelo Platinum
Development Bank of Southern Africa	Sibanye-Stillwater
Digby Wells Environmental	Thungela Resources
Eloff	Trans-Caledon Tunnel Authority
Exxaro	University of Cape Town
GCS Water and Environmental Consultants	University of Cape Town Minerals to Metals Initiative
Golder Associates	University of Johannesburg
International Council on Mining and Metals	University of the Western Cape
International Mine Water Association	University of the Witwatersrand
KLM Consulting Services	Water Institute of Southern Africa Mine Water Division
Merafe Resources	Wesizwe Platinum
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Particular thanks are offered to Ms Sisanda Madiya, a WRC-Water GEP graduate who participated in conducting the interviews for this project and wrote a piece on legislative drivers and barriers to commercialising water innovations in South Africa.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

AMD	Acid MINE DRAINAGE **OR** ACIDIC AND METALLIFEROUS DRAINAGE
AMW	Acid MINE WATER
ARD	Acid Rock Drainage
B-BBEE	Broad-based black economic empowerment
CAGR	Compound ANNUAL GROWTH RATE
CGS	Council for Geoscience
DALRRD	Department of Agriculture, Land Reform and Rural Development
DBSA	Development Bank of Southern Africa
DEFF	Department of Environment, Forestry and Fisheries
DMRE	Department of Mineral Resources and Energy
DSI	Department of Science and Innovation
DTIC	Department of Trade, Industry and Competition
DWS	Department of Water and Sanitation
EIA	Environmental IMPACT ASSESSMENT
EPA	Environmental Protection Agency
EPC	Engineering, procurement, and construction
ESG	Environmental and social governance
eWRP	eMalahleni Water Reclamation Plant
GARD Guide	Global Acid Rock Drainage Guide
GDP	Gross DOMESTIC PRODUCT
GHG	Greenhouse gas
GIS	Geographic information system
HDS	High density sludge
HDTT	High DENSITY THICKENED TAILINGS
ICMM	International Council on Mining and Metals
IIoT	Industrial INTERNET OF THINGS
IMWA	International Mine Water Association
INAP	International Network on Acid Prevention
INCO	International Nickel Company
iTAG	Industrial Technology Approval Group
MBR	Membrane bioreactor
MF	Microfiltration
MINCOSA	Minerals Council of South Africa
MIW	Mining-impacted water
MPRDA	Mineral and Petroleum Resources Development Act, Act No. 28 of 2002, and amendments to the regulations (Amended Regulations) published in Government Notice R420 in Government Gazette 43172, 27 March 2020.
MRL	Market readiness level (also see description in Appendix A)
MWCB	Mine Water Coordinating Body

NEMA	National Environmental Management Act, Act No. 107 of 1998, and amendments: NEMLAA, and Amendments to Schedules 1 and 2 of NEMA (28 February 2014).
NEMLAA	National Environmental Management Laws Amendment Act, No. 25 of 2014 National Environmental Management Laws Amendment Act, No. 14 of 2013 National Environmental Management Laws Second Amendment Act, No. 30 of 2013 National Environmental Management Amendment Act, No. 62 of 2008
NF	Nanofiltration
NGO	Non-government organisation
NMD	Neutral mine drainage
PFMA	Public Finance Management Act
PRI	Principles for responsible investment
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RO	Reverse osmosis
SAIMM	Southern African Institute of Mining and Metallurgy
SD	Saline Drainage
SWPN	Strategic Water Partners Network
TCTA	Trans Caledon Tunnel Authority
TDS	Total dissolved solids
TIA	Technology Innovation Agency
TIPS	Trade & Industrial Policy Strategies
ToR	Terms of reference
TRL	Technology readiness level (also see description in Appendix A)
TSF	Tailings storage facility
UF	Ultrafiltration
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
WDCS	Waste discharge charge system
WRC	Water Research Commission
WULA	Water use licence application
ZLD	Zero liquid discharge

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

This report is the research output of a directed project, for which the Water Research Commission (WRC) published a Terms of Reference (ToR). The following information is excerpted from that ToR.

“The mining industry has for many decades contributed significantly to South Africa’s Gross Domestic Product (GDP). However, this is at an externalised environmental cost including negative impacts on surface and groundwater, poor waste management, acid mine water formation and ecological degradation. Section 28 of the MPRDA imposes full rehabilitation of the mining area on the mine owner; whilst the National Water Act requires that mine owners cease, modify, comply, eliminate, and remedy pollution impacts on water resources. This is applicable during mining operations and on mine closures, whereby closure certificates confirm that the mine owner or holder has met all the environmental, health and safety obligations. As climate change is intensifying operational issues and deepening water scarcity is a driving concern, water sustainability in mining is slowly becoming an industry standard globally, yet remains complex and challenging.

“To comply with the growing regulatory landscape (incl NEMA), the mining sector (land-based, onshore, and offshore) will require access to reliable water supply, technological processes, social innovations and solutions that support environmental and socio-economic objectives in the mining sector. Many of these have been in the pipeline, developed and supported by entities such as the Water Research Commission, Department of Mineral Resources, Department of Water and Sanitation, MINTEK and the private sector. The mining sector globally is considering lower consumption processes and technologies, waterless mines, smart solutions, water recycling initiatives, zero water discharge; advanced treatment technologies and waste management, digitalisation of the value chain and reinforced services. Though the policy and regulatory frameworks of the water, mineral resources and environmental authorities seeks to promote these advancements, it is unclear as to what extent uptake and deployment has been successful in South Africa. Nor has any study been undertaken to unpack the sub-markets within the mining sector, drivers, barriers, enablers, and projected demand for water innovations in the mining sector within South Africa.

“The Global Mining Water and Wastewater Treatment Report 2019-2023 valued the global market at $4,730.2 million in 2018, and expects it to expand by 11% between 2018 and 2023, reaching $7,973.7 million at the end of forecast period. These figures are driven by strong sustainable practices focus and transparency in European markets with high penetration rates of advanced technologies. With North American markets focused on the development of advanced water, wastewater, and AMD treatment technologies. Latin American markets urgently require the implementation of integrated water management solutions. China, India, and Australia are expected to see great investment into membrane technologies, desalination, zero liquid discharge (ZLD), metal recovery technologies, and decentralised treatment solutions for mining in remote locations. Yet, the study found that Middle Eastern and African markets are characterised by weak sustainability approaches to business operations. The growing number of foreign investors and policy shifts is forcing an increase in environmental and social awareness requiring ramped up efficiency and process control solutions.

“The mining sector in general has come under pressure to fast track innovation. A Deloitte study (2016) stated that mining’s innovation has been rooted in a laboratory mindset remaining limited to a focus on technology ignoring broader organisational imperatives and stakeholder sets. The recent regulatory movements in the mining sector have seen widespread realignment of policy in support of inclusivity and transformation, and regulatory development towards sustainable mine closure. The focus on social and environmental impacts through mining operations requires a review of not only a database of water innovations ready for uptake, but how these are deployed into the market and facilitated by the mining sector and water authorities. A second South African team of experts was established in 2019 to address an important public sector-managed component of the market – Acid Mine Water (AMW) mitigation with majority of the issues linked to the consequences of derelict and ownerless mines. The study needs to consider the challenges faced by the private sector and public (government) entities in uptake of solutions, as well as consider the role of civil society."

1.2 PROJECT AIMS

The overarching aim of this study was to improve the understanding of the mining industry and government entities as consumers of water innovations and estimate potential size of the mining water innovations market.

The following were the objectives of the project:

1. Propose a methodology to assess and determine the size and potential of a mining water innovations market;
2. Provide a situational analysis, unpack the characteristics of the market (drivers, barriers, enablers, trends) and provide a demand forecast that considers, e.g. mining sector economics;
3. Undertake a market segmentation analysis in relation to land-based, onshore, and offshore opportunities and impacts, providing a sub-market view for potential uptake;
4. Outline key developments required to improve market structure (supplier, buyer, manufacturing, penetration, affordability, regulatory environment, etc.);
5. Recommend industrial development, process, technological and implementation strategies to be pursued that acknowledges existing regulatory frameworks; and
6. Provide recommendations for future research, policy, and practice.

1.3 SCOPE AND LIMITATIONS

The project was undertaken between March and July 2021 and therefore the exchange rates used, inflation rate and expected growth were based on conditions at that time. In some cases the forecasts used 2019 as a baseline since it was more representative of normal conditions that were not affected by the COVID-19 pandemic that began in early 2020. These exceptions have been noted in the text.

The interview phase of the project included mining companies, engineering procurement and construction contractors, technology developers, researchers, and professional associations. The response rates from the small mining companies were low; 47 mining companies were asked for participation in total but only 15 agreed to be interviewed, almost all of which were large multinational corporate miners. The response rate for the regulators was just 33% and only two interviews took place due to the extent of unease and sensitivity among the people spoken to. Many of the interviewees asked to remain anonymous. This in itself indicates a lack of confidence born of confusion and inadequacy in the regulatory framework in some cases, and in other cases it was a result of an organisational policy prohibiting employees from talking to external parties or the considerable effort required to get such approvals.

The scope was limited to the mining sector in South Africa. The market assessment and forecast therefore excluded mining in other countries, and other sectors in South Africa. However, the market is influenced by related sectors and global trends so these have been defined and noted in section 5.1.

For the purposes of this project, the market for water innovations in the mining sector is defined as the end-users of new water-related technologies, methods, and know-how for the purpose of managing water ingress and egress in voids and pits, and treating mining-impacted water.

CHAPTER 2: BACKGROUND AND CONTEXT

2.1 RATIONALE

Water is one of the most significant issues facing the mining and metals industry and is a critical resource not only for all our members' operations but also for other industries, communities, and the natural environment. There are four key elements of responsible water management in the mining sector:

- Proactive and inclusive engagement with other water users to understand their needs and priorities, share plans and collaborate on managing risks.
- Transparent public reporting on water usage, material water risks and performance.
- Collaborating with other water users to mitigate shared water risks and support equitable access.
- Increasing efficiencies in the use of water (e.g. by maximising water recycling and reuse within mining operations and within catchments where mining operations are located).

Fundamental to this fourth point is the need to consider closure as an integral part of the mine operations' core business, to eliminate the externalisation of water costs and risks and to create a common practice which encompasses the reuse of mining-impacted water for productive use in the post-closure landscape, thereby preventing the creation of more ownerless and derelict mines that become wards of the state. There are an estimated 5000+ ownerless and derelict mines in South Africa, many of which have positive water balances and are sites at which the implementation of water innovations would control pollution and provide water for uses such as agriculture (thus creating rural jobs and food security).

The ToR made reference to the fact that the global mine water treatment technology market was valued at $4,730.2 million in 2018, with rapid growth and implementation of new technologies in Europe, North America, Latin America, China, India, and Australia predicted until 2023 and probably beyond (Frost and Sullivan, 2019). Conversely, African markets are not expected to grow at the same pace despite the global nature of the recent changes in the attitudes of investors and policy-makers towards greater environmental and social awareness and accountability, which require greater environmental and social responsibility.

At the same time, South African mining-impacted water-related research and development activity is prevalent on the global stage. For example, the International Mine Water Association conference of 2020 included research from 32 countries; the most represented country was the USA which contributed 12% of the conference content, and South Africa in second place contributed 11% (Pope *et al.*, 2020). South African authors have provided the majority of the information in the Global Acid Rock Drainage Guide (the *de facto* gold standard for the treatment and mitigation of mining-impacted water) (International Network for Acid Prevention, 2018) and South African mine water treatment technologies such as MiWaTek's zero liquid discharge reverse osmosis have found success in the USA, Germany and Ghana but not here in South Africa (Grobler, pers comm.).

Clearly, there is a pressing need to implement mine water treatment innovations and there is a strong national capacity for R&D of such technologies and know-how. Why then are water innovations not readily taken up in the domestic mining sector?

The WRC funds a strong research portfolio of mine water innovations which is positioned to include applied research as well as blue sky thinking, and innovations addressing minimising the generation of mining-impacted water, addressing the treatment of mining-impacted water (MIW), and addressing its management and productive reuse. However, these innovations are not taken up by the public or private sectors at the rate which could be expected when they reach the commercial or pre-commercial stage of development. The possible reasons for this include the possibility that the innovations do not meet the market need, that the current regulatory landscape does not enable technology uptake, that the political drivers are not correct, that the business and / or environmental cases are not clear, or that the mining companies themselves are not driving uptake for reasons which need to be elucidated.

This project set out to answer the question, “what is the real market for water innovations in the mining sector?” by assessing the South African market for mine water treatment technologies: size of the overall market and how it is segmented, technology users’ needs, drivers for and barriers to technology uptake, and finally the developments required to improve the market’s uptake of mine water innovations.

The overarching aim of the project was to improve the understanding of the mining industry and government entities as consumers of water innovations and estimate the potential size of the South African mining water innovations market.

South Africa’s continued sustainable development has been restricted by its citizens’ and economy’s access to a continuous supply of good quality water. In 2019, South Africa only had 0.2% economic growth, and began the year 2020 in recession. At midnight on Thursday, 26 March 2020, South Africa went into its first lockdown to protect the lives of its people from the COVID-19 pandemic. The national economic response to the resulting damage to the economy entails a social and economic recovery package of R500 billion[1], or ~10% of GDP. Access to a reliable supply of safe water is clearly and directly the key to achieving Sustainable Development Goals (SDGs) 3: Good Health and Well-being, and 6: Clean Water and Sanitation. Perhaps less obviously, this project will contribute to 8: Decent Work and Economic Growth, 9: Industry, Innovation, and Infrastructure, 11: Sustainable Cities and Communities, 12: Responsible Consumption and Production, and 13: Climate Action. The recovery of mining-impacted water and its transformation into clean water for growth and development is an enabler for these SDGs as well as providing for the protection of the terrestrial and aquatic environments.

2.2 OUTCOMES AND EXPECTED IMPACT

This report provides an understanding of mining sector organisations as consumers of water innovations (Chapter 3), an estimation of the current and potential size of the South African mining water innovations market (Chapters 4 and 5), and a set of recommendations for research, policy, and practice interpretation and / or adjustments to enable the implementation of innovations in the mining space as mainstream practice (Chapter 6).

The impact of the project will be a smoother path for mine water technology developers in South Africa to make the transition from research and development to pre-commercial to commercial establishment of much-needed innovations that will enable South Africa to mitigate the risks posed to public and environmental health by the uncontrolled discharge of mining-impacted water.

[1] Billion: the number equivalent to the product of a thousand and a million; 1,000,000,000 or 10^9.

CHAPTER 3: MARKET

The market for water innovations in the mining sector is defined as the end-users of new water-related technologies, methods, and know-how for the purpose of managing water ingress and egress in voids and pits and treating mining-impacted water.

Some of the end-users are the mining companies themselves, some are the engineering consulting companies that support the miners through subcontracting, and some are the public sector organisations and state-owned entities which take on the responsibility of managing South Africa's derelict and ownerless mines, primarily the Department of Water and Sanitation (DWS) and its entities such as the Trans Caledon Tunnel Authority (TCTA). Eskom is a state-owned entity and in terms of innovation need is equivalent to the private sector mining companies, due their owned and tied mines. In terms of market potential however they have been categorised in the public sector owing to their requirements to operate within the procurement constraints of the (Public Finance Management Act) PFMA and its associated regulations.

The mining companies and mine sites where water innovations are needed can be segmented according to their phase of mine life primarily and then according to water balance, age, size, nationality, and commodity.

3.1 WATER TECHNOLOGY MARKET SITUATION

The South African context encompasses challenges ranging in nature from institutional and regulatory to financial and environmental, presently exemplified by the energy crisis and the severe drought affecting a number of areas. The key numbers describing the context (Figure 1) show that current water supply capacity does not meet water demand (both domestic and industrial), and that the priority areas for water innovation investments and deployment fall in urban areas. In general, the COVID-19 pandemic has affected the country very badly: National Treasury announced a GDP contraction of 7.2% in 2020, impacting multiple sectors including mining.

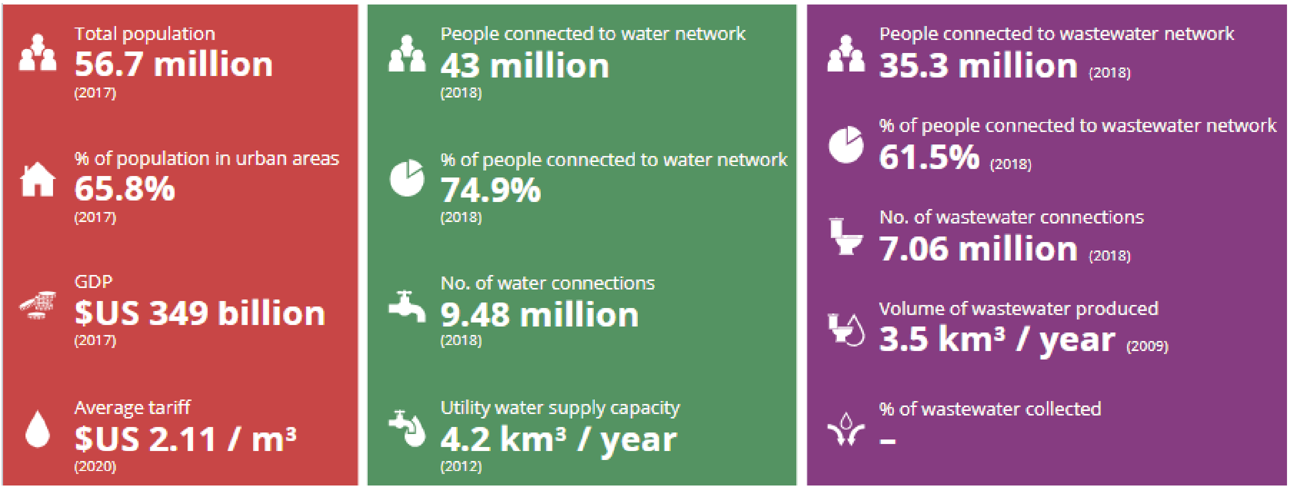

Figure 1: Key statistics of the water sector

A map of active mining licences (Figure 2) shows that there are 4006 onshore (and two offshore) sites which are currently or potentially being actively mined.

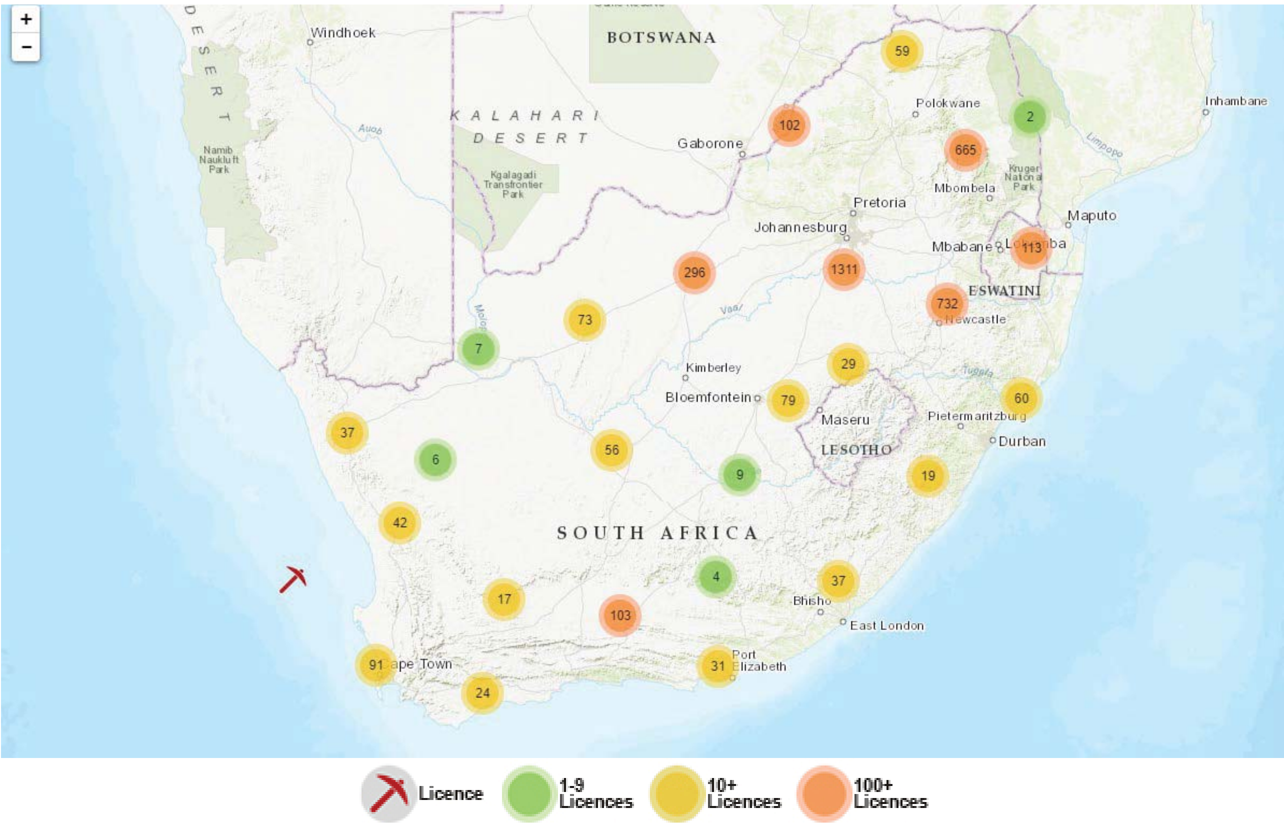

Figure 2: Map of active mining licences in South Africa (published 2018 and continuously updated; this version as at 25 June 2021 (Oxpeckers Center for Investigative Environmental Journalism, 2018)

3.2 PRIVATE SECTOR TECHNOLOGY END-USERS

Large-scale private sector participation is likely to remain limited in the near term because of traditional resistance and concerns about bankability, although as per the 2019 budget, it is the government's stated ambition to increase blended finance in infrastructure spending (mixing private finance and funding from development finance institutions). Along with long-term reforms on how the municipal sector is managed, initiatives such as the establishment of an independent, effective regulator will help reassure investors.

The biggest opportunity for private investment will be in non-conventional infrastructure projects such as desalination and reuse. EThekwini Metropolitan Municipality is notably looking to renew its successful 20-year build-operate-transfer (BOT) Durban Water Recycling (the contract ended on 30 April 2021). The municipality is also pushing ahead with four more reuse BOTs and is considering a large-scale desalination plant under BOT. The City of Cape Town has also indicated it would consider procuring its large-scale desalination plant as an independent water producer (IWP). The government's legacy AMD desalination project will also involve private finance. eMalahleni Municipality obtains potable water from the eMalahleni Water Reclamation Plant (eWRP), a reverse osmosis (RO) treatment plant.

The development of the eWRP in 2006 / 07, with a CapEx cost of R296 million, was beyond the capability of the eMalahleni Municipality to fund or implement. The municipality therefore entered into a public-private partnership (PPP) agreement between themselves, Anglo American Thermal Coal and BHP Billiton (Garner and Naidu, 2013). The plant is now owned by Thungela Resources, recently demerged from Anglo American (June 2021). Keyplan (later bought by Aveng Water) was contracted to design, build, operate and maintain the plant (Günther and Mey, 2006). The eMalahleni Municipality buys 50 Ml/d potable quality water supplied by the eWRP and blended into the distribution network.

Outside of the gold fields, there remains interest in small-scale containerised AMD treatment solutions, as well as low chemical or non-chemical solutions. These could be implemented at numerous smaller mines and are more cost-effective than a large-scale counterpart. AMD treatment also offers potential opportunities for the development of direct potable reuse schemes exemplified by the eWRP.

There were 784 listed mining companies active in South Africa in December 2020 (Garside, 2020) which should indicate 784 potential private mining sector organisations which are buyers of, or investors in, water-related innovation. However, their attitudes range from total disinterest in water innovations to a willingness to invest in innovations as early as technology readiness level[2] (TRL) 2 to 4 in order to guide the innovations' development towards deployment on the mining companies' own sites in the decades to come.

Those which expressed their lack of interest in water innovations cited the following reasons:

- no budget nor any prospect of a budget for anything more than minimal water management and treatment activity;
- firm conviction that conventional water management, treatment and monitoring methods and technologies are sufficient;
- an overall negative view of the future of mining in South Africa as a whole and the absence of any feeling of control that would enable them to improve the situation;
- acknowledgement that anything to do with water except for maintaining the volumetric water balance is a grudge purchase, so the quickest, cheapest available solution is always bought;
- experience of inadequate enforcement of regulatory requirements, such that not even the legal minimum action to mitigate water risks has been taken.

Innovation in relation to water in mining companies active in South Africa is stifled. Interviews with numerous companies of all sizes and mining various commodities demonstrated that activities are in general poorly aligned with those expected in a traditional innovation cycle (see Figure 34, in Appendix B). There is also a stark difference between operational activities and site closure activities in terms of how water is budgeted for and managed from an innovation perspective. Operationally, water is seen as a key issue (and therefore the management from a resilience, sustainability, and environmental impact of it is budgeted for through incorporation into the operational activities utilising water), whereas on the closure side, water is the highest cost involved in legacy management and requires large financial commitments in perpetuity.

Engineering consultants are not the final market. The market in terms of engineering consultants that support the mines with water management and treatment extends only to the clients to which the engineering consultants can supply innovations. To some extent the engineering consultants could potentially be considered as a market in their own right if they have interests in acquiring licences to new technologies, but through the interviews it became clear that they primarily develop their own technologies and know-how to respond to the immediate demands of a specific site. We have therefore excluded engineering consultants as an end-user market. If they implement innovations in the mining sector in other countries or for South African clients in other sectors, then that implementation does not form part of the South African mining sector. Therefore, we remain with a theoretical maximum possible number of investors / user organisations in the private sector of 784 and a realistic maximum of far fewer.

3.3 PRIVATE SECTOR MARKET SEGMENTATION

At the beginning of this chapter we stated that mining companies can broadly be segmented according to their water balance (linked to location), their age, size, nationality, and commodity. The segments are not easy to categorise because they overlap, but they have been summarised in Figure 3.

[2] TRL definitions are provided in section A1 of Appendix A.

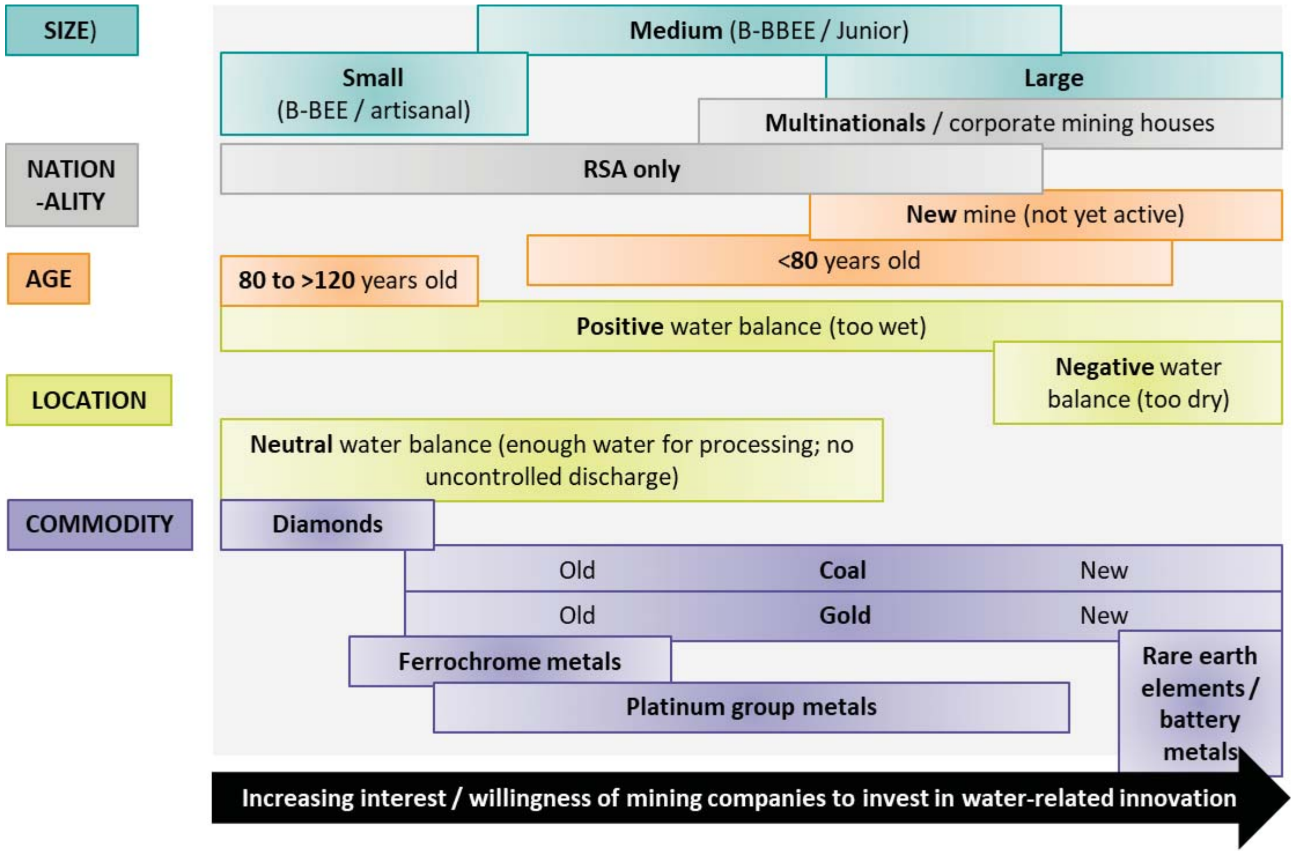

Figure 3: Mining company attributes that determine their level of willingness to implement and / or invest in water innovations, e.g. a large multinational mining company working on a new site that has a water imbalance is the most likely to invest in water innovations.

3.3.1 Size

Generally speaking, larger mining companies have more resources both in terms of finances and skills available internally than smaller companies and hence greater capacity to spend. Larger companies are also more likely to be multinational and have their social and environmental performance driven by shareholder incentives, thus also be more likely to spend the resources they have.

The levels of interest among medium and small mining companies were personality-driven. The trend that emerged was that the junior and artisanal mines can either be more willing to take risks and trial emerging technologies because they are not hindered by a fear of shareholder anger if the technology does not work, or conversely can also be content to let the multinationals invest in the research and development phases and wait to be second wave adopters of new technology and know-how.

It should be noted that ‘size’ can be deceptive. Many smaller mining companies are formed when the multinationals divest parts of their businesses. More than one interviewee commented that the corporate mines deliberately demerge their less profitable business units under the disguise of supporting B-BBEE and knowingly sell liability sites to naïve owners who do not fully understand the magnitude of the problems they have bought and are not equipped with the funds or skills to adequately handle the legacy water issues.

3.3.2 Nationality

Multinational corporate mining companies which are listed on the Johannesburg Stock Exchange and other stock exchanges are more open to the idea of innovation than those that are only locally owned because their shareholders hold them accountable against corporate goals that are frequently aligned with the most stringent of national legislations across their countries of operation. South Africa's poor enforcement of legislation arose repeatedly as a reason why mining companies do not take enough interest in innovation: they are not compelled to by the regulatory framework. They also find it more difficult to implement innovation on their sites than the locally owned companies because they have a higher administrative burden of doing so.

Again, the note on 'size' applies here because several small and medium mining companies are in fact fragments of large multinational mines.

3.3.3 Age

Older sites which are already in the process of closure, or decommissioning approaching closure are unfortunately the least open to innovation despite needing it the most. This is because sufficient financial provisions for environmental rehabilitation and long term site management were almost always not made at the start of the mining cycle. Older mines have invested more heavily than new ones in their existing infrastructure and suffer more from the sunk cost fallacy when considering making infrastructural changes.

The age of the mine is connected to the commodity, with ferrochrome metals, diamonds, gold, and coal being the longest-mined commodities, then platinum group metals. Rare earth elements such as lithium are associated with the newest sites owing to the recent acceleration of the uptake of renewable energy technologies that require energy storage. The newest sites are the most open to innovation and willing to invest in implementing it.

3.3.4 Location

Location and commodity are linked because commodities are obviously mined where they occur. Location dictates water balance. This means that platinum group metals and diamonds which occur in arid areas and therefore usually have negative water balances are open to innovations for the purpose of water conservation and demand management, on-site reuse, and dry processing. Mines where there is a positive water balance require pumped dewatering during mining in order to access the mineral reserves and therefore *should* be interested in innovations for mine drainage treatment and management and prevention. That is not guaranteed, though: some of them merely pump the water up and let uncontrolled discharge or discharge into holding ponds take place without attempting to minimise the volume of water entering the mine (ingress control) or to treat the water pumped out.

3.3.5 Commodity

Commodity is linked to the location and age of the site. Maps illustrating the intersection of location and commodity are shown on the following two pages. Diamonds (Figure 4) and platinum group metals (Figure 5) are mostly mined in dry areas and suffer from water shortages, making them disinterested in mining-impacted water prevention, minimisation and treatment technologies but interested in water reuse and dry processing innovations. Gold (Figure 6) and most coal mines (Figure 7) are more widespread and can be too dry or too wet, generating a need for innovations to prevent mine ingress, manage and treat mining-impacted water, reuse water onsite and between sites, and use water productively in the post-mining landscape. However, the older mines did not set the financial provision for investing in innovations at this stage of the life-of-mine aside in the mine planning phases.

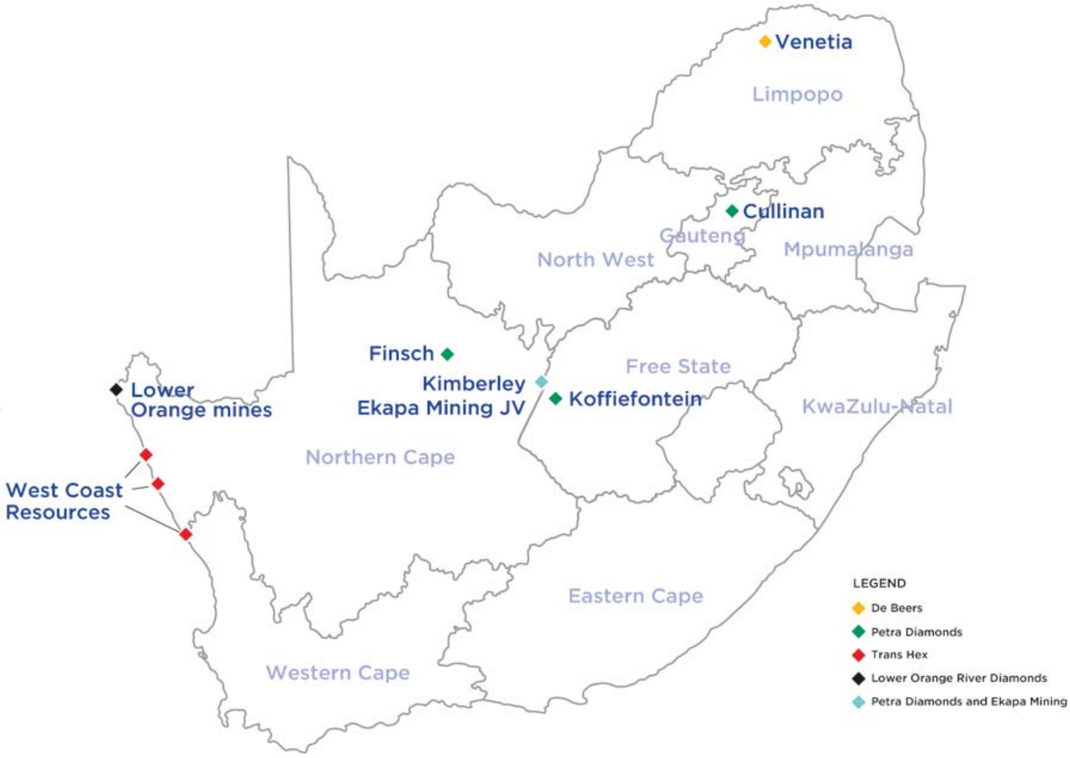

Figure 4: Location of active diamond mines in 2020 (Minerals Council South Africa, 2020b)

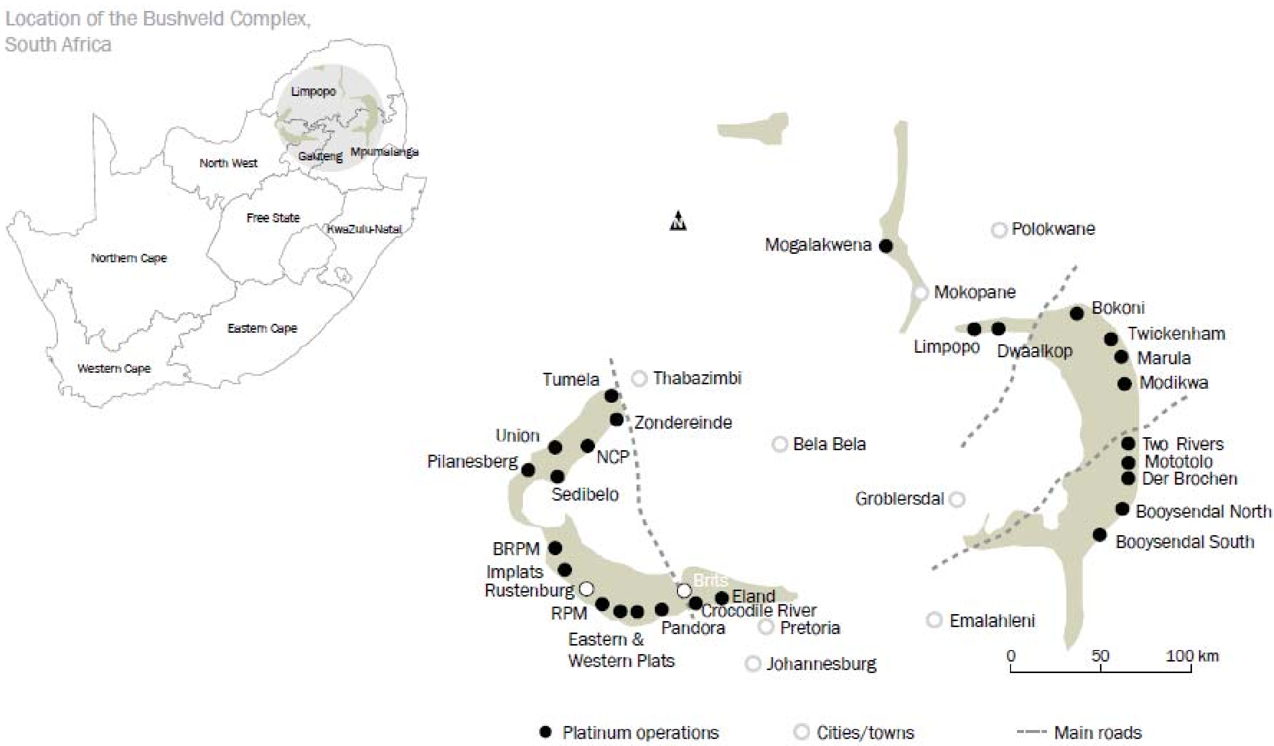

Figure 5: Location of the platinum group metal ore bearing Bushveld Complex and active mines within the Bushveld Complex (Minerals Council South Africa, 2021)

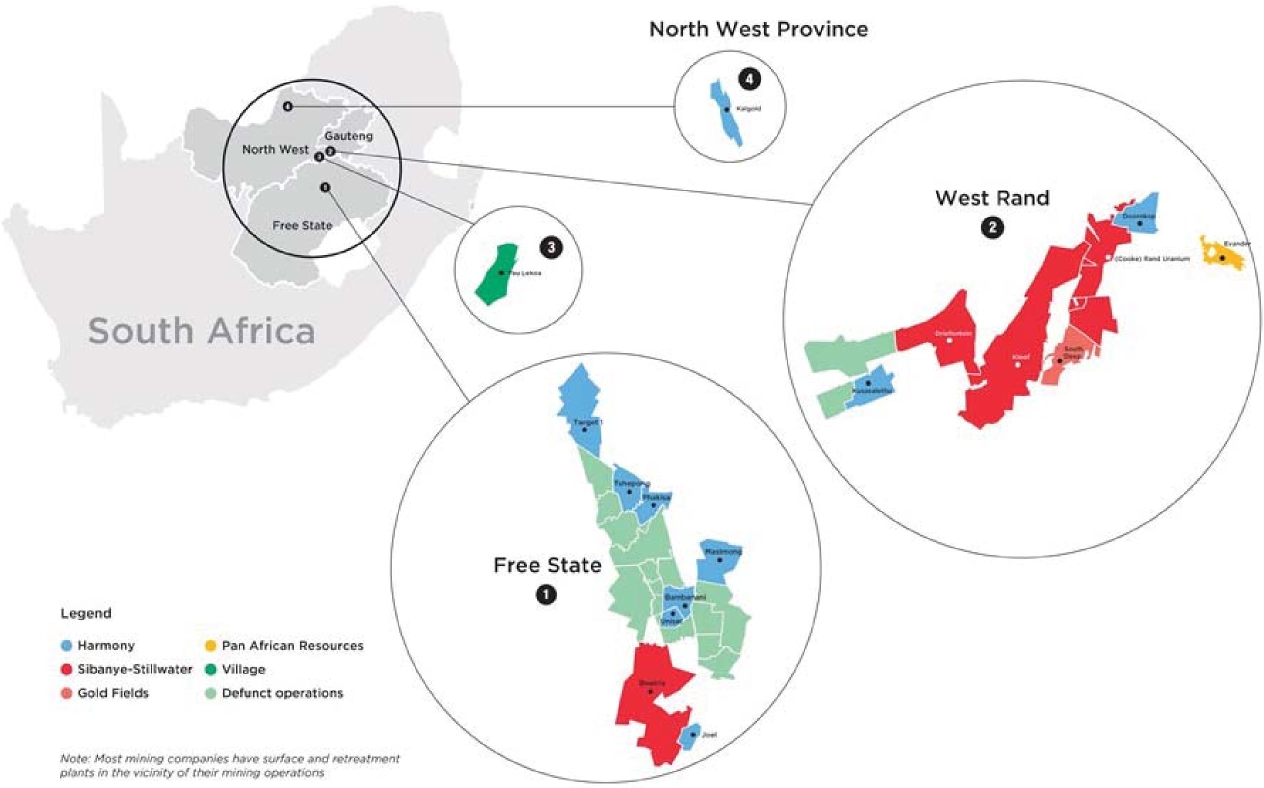

Figure 6: Gold mine locations in central South Africa (Minerals Council South Africa, 2020c)

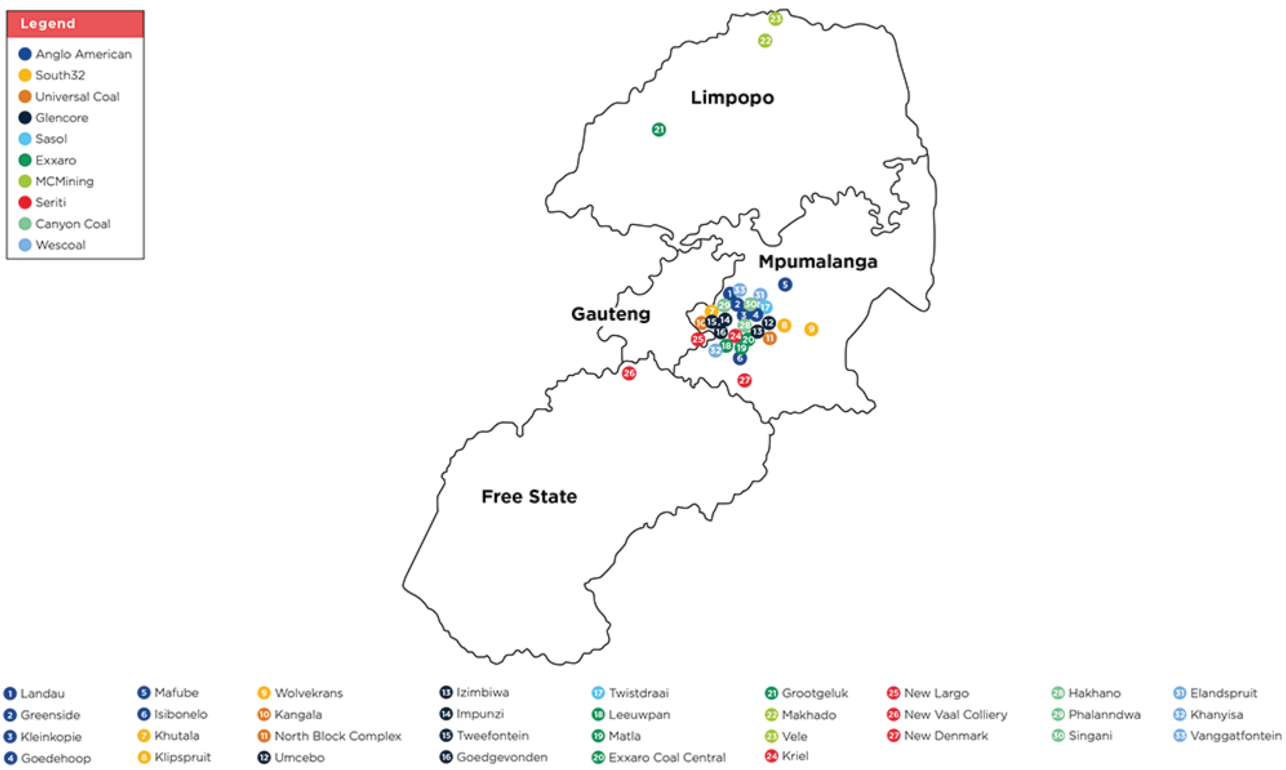

Figure 7: Most of the significant coal mines in central South Africa, excluding eastern mines (Minerals Council South Africa, 2020a). Anglo American Thermal Coal has demerged since this map was drawn and its sites are now the property of Thungela Resources (as of 7th June 2021).

The most open to innovation are the rare earth element mining companies. Their businesses are based on renewable energy and they see themselves as a green sector. This gives them a completely different mindset to the legacy miners. They are aware of the catastrophic environmental impacts of the older mines and bring closure planning into their mine plans from the very outset. The diamond industry was the least interested in water innovations; this is influenced strongly by the fact the most diamond mines are either offshore or in deserts where water scarcity is the problem rather than the need to minimise water ingress into voids and treat mining-impacted water.

Most important of all is the phase of life of mine: closed mines have an urgent need for water innovations in perpetuity but that need does not currently translate into a market due to the barriers described in section 4.3.2 and the restraints in section 5.5. Operational mines (including all the phases from #2, mine planning to #5, decommissioning, shown in Table 1) also have immediate needs for water innovations and have owners that can and should be actively engaged in water management and treatment.

Table 1: Mine phase objectives and activities

Mine phase	Primary objectives	Typical water-related activities
1. Exploration	• Discovery and mapping resource (e.g. ore deposits)	• Geological and hydrogeological mapping. • Surface geochemical sampling. • Subsurface sampling (drilling, exploration pits, adits, shafts).
2. Mine planning, feasibility, and design	• Assess the economic viability of mining	• Develop mine and waste management plan. • Characterise baseline conditions including groundwater and surface water. • Environmental and soil impact assessments. • Design mine layout including water ingress prevention.
3. Construction and commissioning	• Construct facilities and infrastructure for mining	• Construct infrastructure (incl. water supply). • Construct processing, water treatment and waste processing facilities.
4. Operation	• Extract and process ore deposit	• Water ingress prevention. • Resource and excavation dewatering. • Develop waste facilities (rock dumps, TSFs, leachate dams). • Reuse and recycling of process water. • Wastewater and MIW treatment.
5. Decommissioning	• Site closure: re-establish pre-mining conditions to the extent possible; at the least create conditions suitable for post-mining land use	• Site reclamation (covers, pumping stations). • Ongoing MIW treatment.
6. Post-closure	• Land use commensurate with landowner's desire and adjacent land uses. • Long term management of environmental impacts.	• Ongoing MIW treatment. • Ongoing environmental sampling. • Site redevelopment. • Long term maintenance of waste storage facilities.

3.4 PUBLIC SECTOR

In addition to the 4004 onshore active mines, there are thousands of ownerless and derelict mines which have been abandoned or closed without certification from the DMRE and their owners liquidated, and which are now wards of the state (Figure 8). Estimated numbers vary from 4900 to 7000 mines (Council for Geoscience, 2018; Govender, 2021). These mines include almost every mineral commodity that has ever been exploited in South Africa. Thus there is a need for water management, treatment, and monitoring at somewhere between 9000 and 11000 sites that should convert to market pull, or demand for water innovations. All of these ownerless and derelict sites are in phase 6 of the life of mine (Table 1).

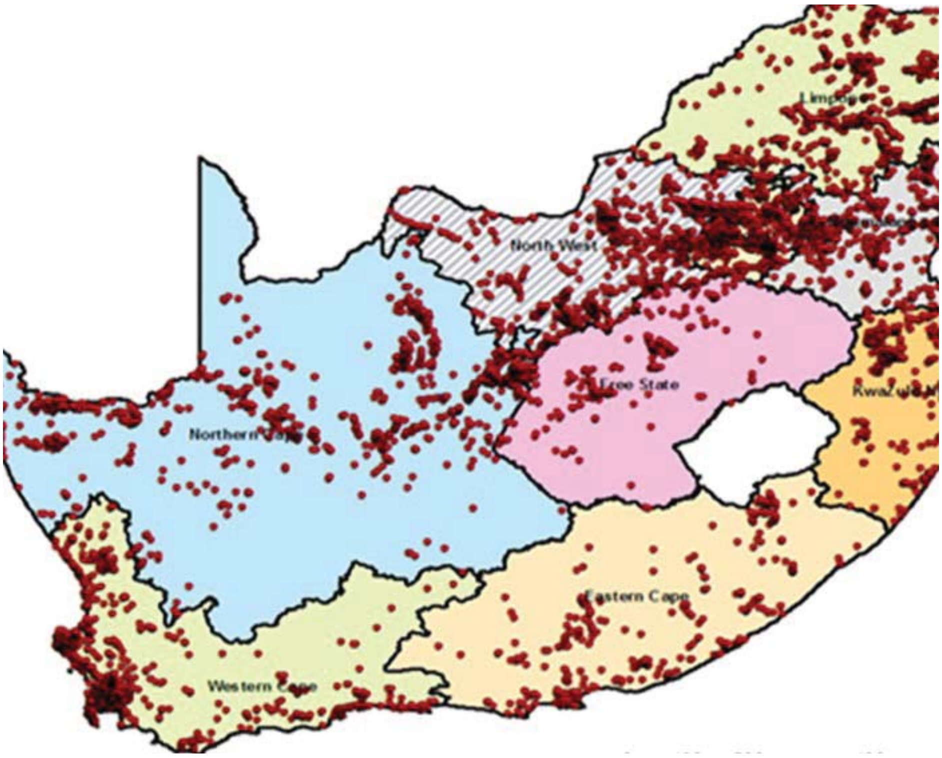

Figure 8: Locations of about 6000 derelict and ownerless mines in South Africa (Council for Geoscience, 2018)

In accordance with the South African National Development Plan, raw, bulk, and water service infrastructure and sanitation remain a key focus of government investment in the water sector and an area of relatively stable activity. The supplementary budget review for 2020 issued in July 2020 in the wake of the COVID-19 pandemic showed only a slight decline in the allocation for water and sanitation; the Medium-Term Policy Statement released in October 2020 showed virtually no adjustment to spending in water and wastewater for 2020-2021.

Thus the overall prospects for the medium term remain good: although the National Treasury is planning significant reductions in spending to compensate for rising debt servicing costs, the government wants to protect capital spending (the biggest adjustments will come through employee compensation) and community development (such as access to basic services, road development, etc.) will be protected in line with the country's economic recovery plan.

The primary focus is on water and sanitation services infrastructure rehabilitation, including smart water opportunities. Current financing mechanisms are not conducive to such investments but increasing awareness and pressing water scarcity issues are likely to deliver reforms in the medium term. For example, the Development Bank of Southern Africa (DBSA) is working on the design of a national non-revenue water (NRW) programme that would feature a centralised office and widespread standardisation of NRW best practice /

initiatives, including performance-based contracts. The programme design was expected to be completed by the end of March 2021.

Water security is an increasing concern towards 2030. To address a projected deficit of between 2.7 and 3.8 billion m^3 / y, alternative water sourcing options are actively being explored. Reuse of wastewater, and non-domestic wastewater in particular is being more actively pursued than seawater desalination as it is cheaper and not restricted to coastal areas. The National Water and Sanitation Master Plan plans to increase reuse capacity from 1.3 billion m^3 / y in 2015 to 2.1 billion m^3 / y by 2040, and desalination capacity from 90 million m^3 / y to 300 million m^3 / y. The underground water resources that mine drainage provide are therefore valuable resources and coincide with the large inland industrial complexes which exert the highest water demand.

The public sector plans to desalinate legacy AMD in the Witwatersrand basins are a strong pull for treatment innovations, but implementation is hindered by a lack of clarity around which organisation(s) are liable for the water treatment costs and which are able to use the treated water. One or two plants would treat up to 180,000 m^3 / d; the plant(s) would likely be financed through public-private partnership (PPP) models (concession / lease, design-build-operate-maintain-finance).

Although ownerless and derelict mines are the responsibility of the South African government and many of these operations represent significant risks to public health, safety, socio-economics and the environment, the number of sites is an overestimation of the market. There are opportunities in the post-closure aspects of mining (see section 4.4.6 Mine closure and site remediation) but they are severely constrained.

The authorities instituted a programme in 2010 funded by the DMRE (Department of Mineral Resources (DMR) at that time) and implemented by the Council for Geoscience (CGS) to address the risks at these operations by implementing rehabilitation activities to effect closure. Given the health risks, such as asbestosis, mesothelioma, lung cancer and pleural plaques of communities exposed to asbestos fibres, the DMRE initially focused its attention on asbestos mines.

In 2013, SRK was appointed to provide engineering and design services for the rehabilitation and ultimately the closure of several abandoned and derelict mines throughout South Africa. Mitigation of risks was then utilised as the basis of the conceptual design and ultimately the final design for the remedial measures. A phased approach was adopted where various possible conceptual closure designs were considered and then assessed against practicality, cost, and ability to mitigate risk and achieve the desired closure objective. The closure activities included sealing the means of water ingress and egress from the workings. The programme has been hindered by a lack of funds made available to the CGS and lack of access to those funds which are available, due to the extreme difficulty in navigating the procurement processes of the PFMA and its regulations.

In total, SRK has overseen design-to-construction water management or treatment projects at a total of 13 derelict mines since 2013.

3.5 WATER-RELATED SPENDING CAPACITY

The current operational expenditure by the South African mining industry on water management and MIW treatment is summarised in Figure 9. The impact of the COVID-19 pandemic and suspension of mining activity under lockdown can clearly be seen by comparing 2019 and 2020. The current prediction for OpEx by the mining industry in water-related operations in 2021 is R3.8 billion (R3,845 million) (Brown, 2021).

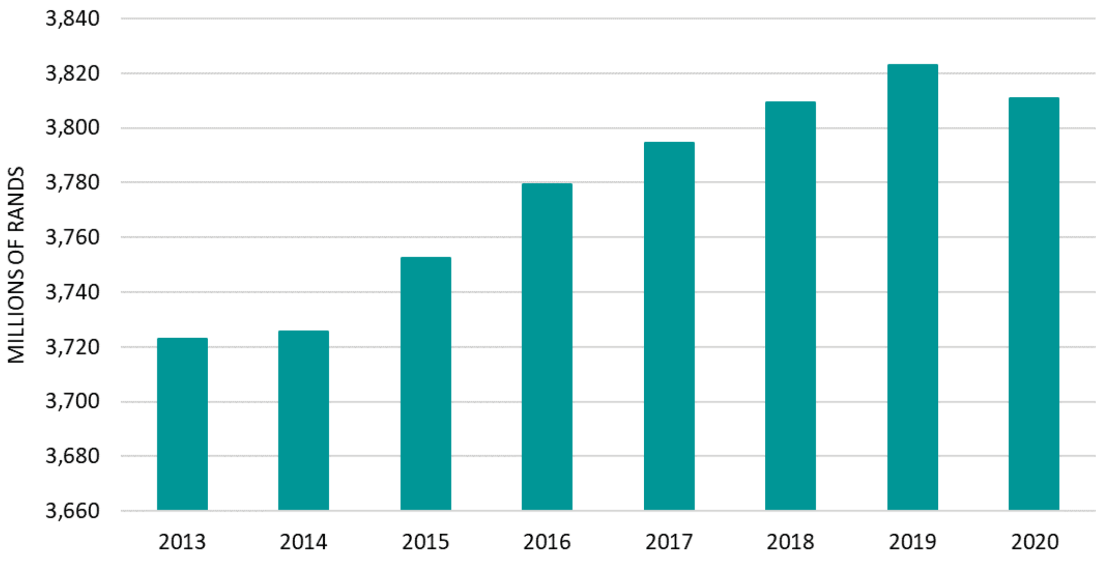

Figure 9: Total water-related OpEx in the mining industry during 2013 to 2020 (Brown, 2021).

The OpEx data typically do not include investment into innovative technologies. The data reported in Figure 9 include equipment that can be considered consumables, and chemicals as listed in Table 2.

Table 2: Products included in OpEx data

Equipment	Chemicals
Chemical feed systems	Biocides
Other equipment	Other chemicals
Agitation / mixing / settling	pH control
Low pressure membranes (microfiltration / nanofiltration)	Scale inhibitors
Pumps	Corrosion inhibitors
Valves	Coagulants
Pipes	Flocculants
Non-membrane filtration	
Automation / control	**Other project costs**
Sensors	Civil engineering / fabrication
Testing / analysis	Design and engineering services
Disinfection	Regulatory and professional services
Screens	
Activated carbon	
Gas flotation	
High pressure membranes (reverse osmosis / nanofiltration)	
Ion exchange	
Other sludge stabilisation	
Aeration	
Sludge thickening / dewatering	
Thermal process equipment	
Anaerobic digestion	
Sludge drying / thermal processes	
Electro-deionization / electrodialysis	
Oil-water separation	
Equipment	
Meters	

Total CapEx for the period 2013-2020 is shown in Figure 10. The categories of capital items included in this total are physical / chemical treatment, fluid handling, dissolved solids removal, digitisation, biological treatment, disinfection, and sludge management.

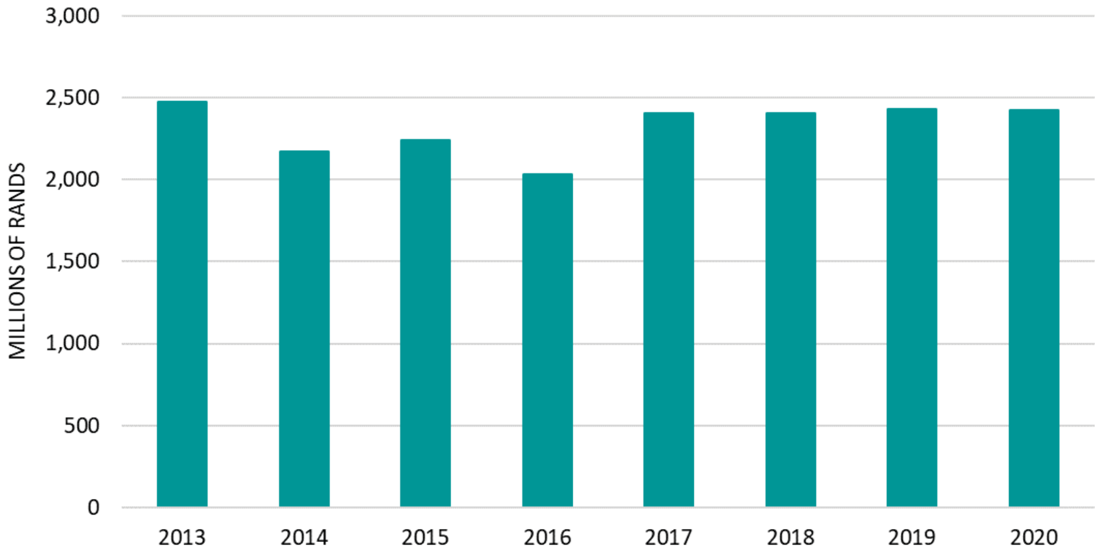

Figure 10: Total water-related CapEx in the South African mining industry during 2013 to 2020, excluding general construction / other civils expenses (Brown, 2021).

The CapEx totals for the past five years (2016 to 2020) provided in Figure 10 above are itemised in Figure 11 (next page). The most striking trend from year to year is the remarkable consistency of the composition of the total CapEx, over the same period in which the total varied by nearly R400 million.

The largest CapEx component by value of investment is fluid handling, a category that includes pumping surface water from place to place and controlling the discharge of MIW above ground as well as in subsurface voids.

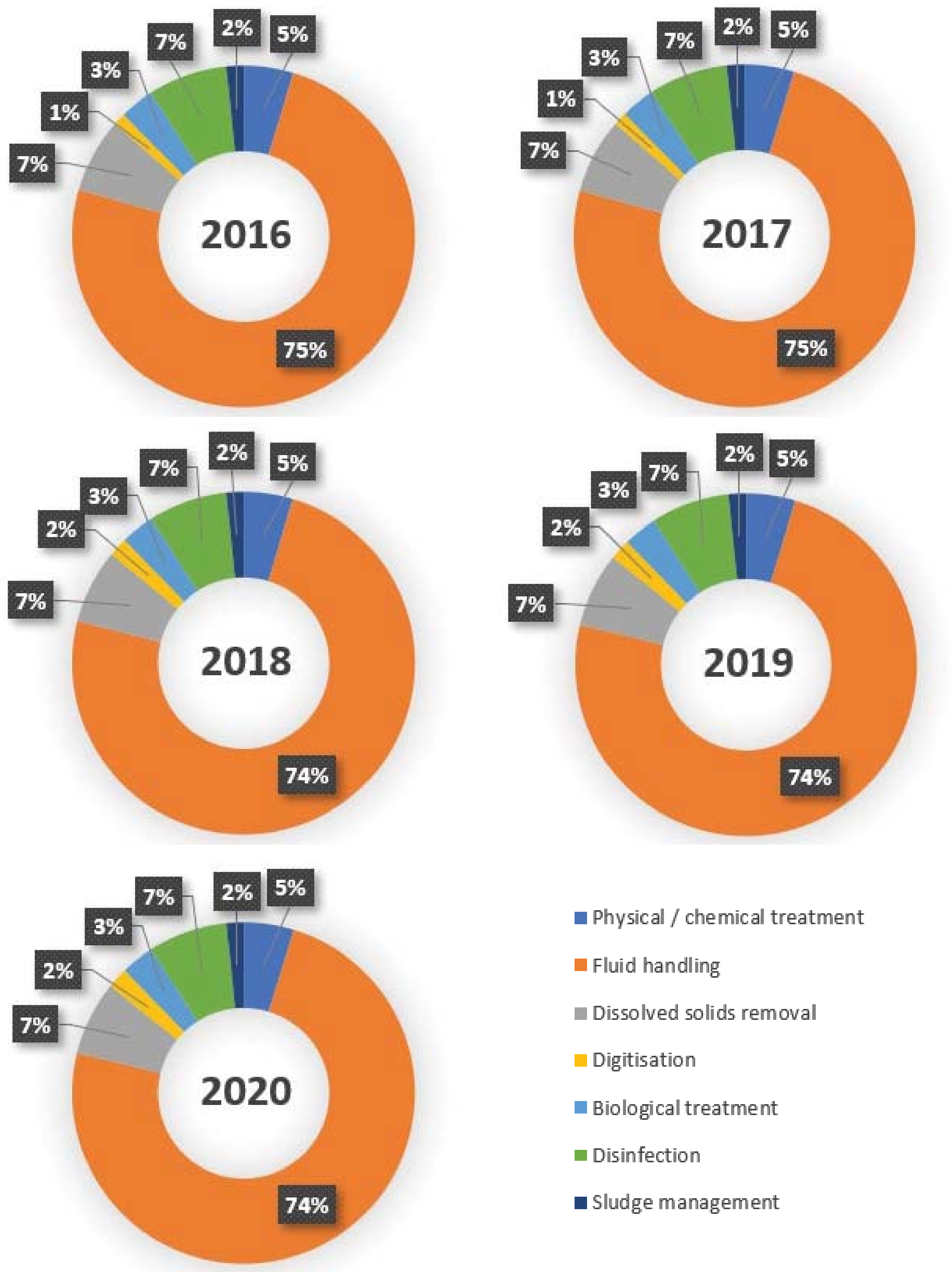

Figure 11: Breakdown showing the proportion of CapEx accounted for by each category of capital item during 2016-2020 (Filou, 2021).

CHAPTER 4: OPPORTUNITIES

4.1 CURRENT OPPORTUNITIES

This section deals with innovation generation, selection, and uptake with a focus on need rather than market. Sections 4.3, 5.4 and 5.5 deal with non-technical influences on market versus need, and on market drivers and restraints respectively.

Current market opportunities are primarily driven by the presence or absence of water (supply), regulation and corporate social responsibility. Structured interviews were used to determine the high level innovation processes adopted across the sector. The findings are summarised below in line with the widely acknowledged innovation cycle as it is supposed to function (depicted in Figure 34, Appendix B) and visually presented in Figure 12 to quickly identify areas of strength and opportunities for improvement.

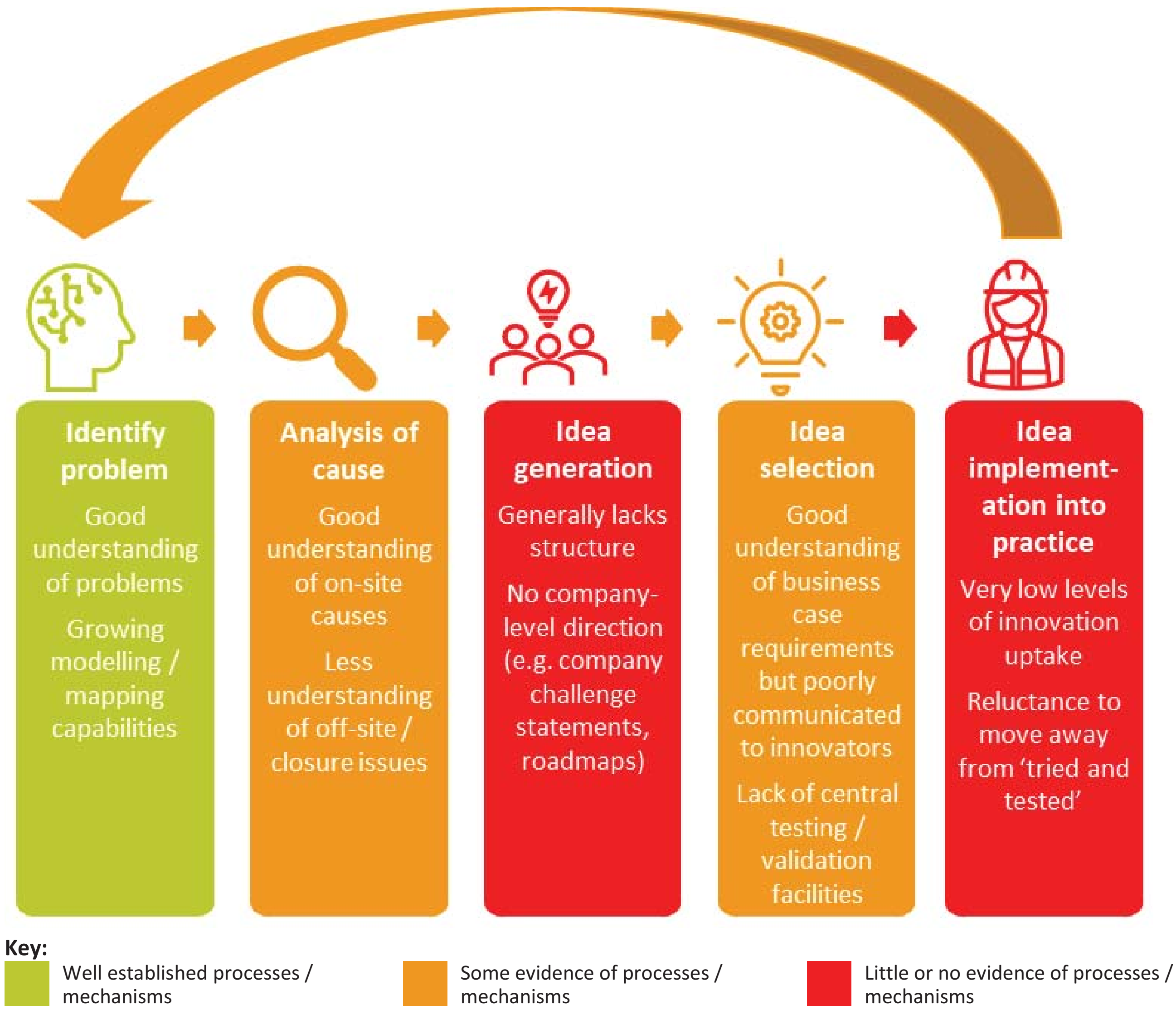

Figure 12: Features of the innovation cycle revealed in the South African mining sector

4.1.1 Problem identification (innovation cycle step 1)

All of the mining companies spoken to have a good hold on the problems and impacts of current operations. Their technology and know-how needs to identify the problems include:

- Modelling. Generally undertaken by external consultants, including surface and groundwater balance models, therefore the number of sites or mining companies exceeds the number of technology users, since most consultants serve multiple mining companies.
- Use of GIS systems to map and record impacts / problems. In some cases, whole catchments are mapped and they understand water quality and quantity impacts.
- Ongoing risks are quantified and managed, sometimes with the help of risk departments, so that priorities can be established.
- All manage the problems identified in line with their water use licences.

Legacy sites were less well understood, with a significantly reduced use of modelling, GIS and supported risk assessments being implemented. One organisation has recently begun the roll out of GIS on closed sites, but these activities have not yet reached their South African sites.

There was evidence of negative impact from the lack of funding available to the municipalities (which is out of the mining companies' control), however, this appears to be having an impact on the mining companies ability to contribute positively (through their Social Community Plans) to the sustainable development of the communities in which they operate. Examples provided included mining companies stepping in to pay for new roads, hospitals, and bakeries for local communities because they believe this is required and will help the local communities. However, in one example (due to lack of consultation) the hospital was built too far away from the residential areas, and the community really wanted / needed a local clinic rather than a hospital. In another, a bakery was built for the local community, however the local community did not want or demand supplies of bread products, the employees lacked the skills and experience to operate the business and so the bakery failed.

These examples highlight the need for better provision for and collaboration for identifying the local, community based problems that the mining companies have within their gift to influence, including the need for local skill development and upskilling and mentoring of local municipalities, etc.

In general, the mining companies understand the problems created by their processes, but lack understanding of the more holistic challenges being faced by the communities within which they operate despite international best practice focusing on catchment-level management (e.g. driven by the ICMM).

Lastly, the miners' idea of what an innovation is in this application is far from what the consulting companies with significant R&D activity would consider innovative. Some mines and engineering consultants named off-the-shelf equipment like drones for aerial photography to map impacts / problems as innovation and considered themselves as highly innovative by virtue of buying a drone.

4.1.2 Analysis of cause (innovation cycle step 2)

From an operational perspective, the mining companies have a good understanding of the (water related) problems experienced on their sites, and why they occur. There was less understanding of the problems encountered by the surrounding communities and on surrounding land, and how they see and feel the problems impacting them – particularly around closed mines.

This leads the mining companies to be willing to purchase and implement water technologies that deal with their immediate on-site water challenges on currently operating mines and for new mines, but less willing to test and develop ideas around water risk mitigation for the post-mining landscape.

Legacy sites can be further complicated by the ancestral land claims process currently underway. An example provided was where 55,000 hectares of land has been laid fallow for 25 years. The land incorporates legacy mining sites either within, or on the very periphery of the land boundaries. The new owners of the land want to develop agricultural revenue sources, including farming food crops for human and livestock consumption, however the suitability (as a result of historic mining) of the land, surface and groundwaters is not clear. In this, and similar situations, the causes of the problems being experienced are therefore not well understood and there are not sufficient resources available to effectively investigate. The water-related innovation needs cannot be separated from the other issues at play.

4.1.3 Idea production (innovation cycle step 3)

Very few of the companies spoken to have formal or recognised internal mechanisms which empower and reward ideation.

One exception is a company that has internal innovation competitions through which the CEO awards funding to strong ideas. They also have a system whereby employees submit ideas to a platform which engages company experts to assess the ideas. Ideas of value are then put to an internal investment committee for funding. Neither of these internal schemes have a focus on water though.

Typically, operational water related challenges are solved using off the shelf solutions provided by large companies such as WSP, SRK and Veolia. Closure sites require a different approach and much longer timescales. For closure sites, it is not uncommon for mining companies to try and anticipate the challenges and plan ahead – they do this by (sometimes) working with solution developers ahead of needing them. Through this approach, many more solutions are reviewed via a screening process and subsequently assessed for potential suitability. Uptake of these solutions is then impacted by the barriers to innovation discussed later in this report.

No mining company spoken to sets or promotes challenge statements or provides water innovation roadmaps to their supply chains so that they can collaboratively develop solutions.

During several interviews, Coaltech research association competitions were referred to as being a key source of ideas for potential solutions. This signals the need for similar collaborative approaches for other segments of the mining industry, because Coaltech is limited to coal miners.

Consultants were referenced by all the mining companies spoken to as a key source of solution ideas, particularly mentioning the value of receiving details of pre-screened solutions, making their internal decision making and risk assessment processes more streamlined and efficient.

The consultants we interviewed provided a consensus viewpoint that they could be more innovative if their mining company clients would let them. Several interviewees described being able to build and operate “a few” lab and pilot scale plants to test novel technologies for water reuse in commodity processing (e.g. flotation, ozonation) funded by internal funds from the mining companies. They stated that all of these pilots were focused on incremental improvements on existing technologies.

Their mining clients are interested in innovation but they are pushed to implement solutions that work as quickly as possible, and piloting innovations takes too long. The risks presented by non-compliance and, in the multinationals the need for positive public relations, push them towards proven options to be implemented quickly with no reputational risk. The engineering consulting firms need cash flow; R&D projects take too long and do not guarantee a solution to a problem so they bring in off the shelf technologies and optimise them.

4.1.4 Idea selection (innovation cycle step 4)

Most of the mining and engineering companies spoken to had very similar criteria for selecting potential innovative water solutions for the operational and closure sites. These include:

- Evidence of a strong, well thought through and aligned business case (i.e. the innovation must either enable the mining company to increase performance with no increase in costs or to maintain performance while decreasing costs);
- Credibility of the technology provider – can they verify the data and performance they are claiming with case studies, data sets and references from previous trials / clients?
- Cost benefit analysis – is there the potential to generate revenue from the application of the new technology, e.g. through (enhanced) resource recovery;
- Does the solution guarantee compliance with the regulatory requirements? How would the solution impact operational / legacy management risks?
- Are the Health, Safety and Environmental performance credentials sufficient?
- Does the solution enhance / impact local biodiversity and / or Greenhouse gas emissions?
- Can the solution be deployed as a standalone element, or does it work in combination with existing / other planned new infrastructure?
- What TRL is the solution? The lower down the scale, then the more sceptical the technology users are (for operational applications in particular). TRL4 or 5 is required as a minimum.

There were two notable exceptions: one multinational (BHP Billiton) and one rare earth element mining company were keen to comply with all legislation and policies in all their countries of operation even though the South African regulations have not been well enforced. They are more forward-looking in general. For example, they are aware they will need to treat a specific water in 18 years' time so are already looking for suitable technologies to use for that water and are willing to invest in the development of technologies presently at TRL2-3 so that they will be ready in 18 years' time, as well as being interested in learning about innovations which are already at TRL7-9. These companies are actively engaged with research centres in universities, they attend and present at applied research conferences (e.g. the SAIMM symposia) and have partnerships with research organisations such as Mintek and the CSIR.

In general though, pilot / trial programmes are used by the mining companies to verify an existing solution's performance capabilities for their own site and purpose. Through discussion, it appears that if a physical solution is being investigated, it is more likely to be trialled on one of their own sites. If it is a biologically based solution, there is a greater need for off-site pilot locations. In general, pilots or trials take place in one or more of the locations described below:

- **Mines** – trials may take place on the site of an operational / legacy mine. Typically, this will involve creating a test bed alongside a water source and other normal activities.
- **Universities** – lab scale / small pilot scaled pilots often take place in universities. To verify the performance of the selected solutions being tested, mining companies will ship raw water to them.

- **Suppliers** – in some cases the mining companies utilise R&D sites provided by their suppliers. A specific example of using a supplier's biological treatment R&D Centre was provided by one interviewee. In this instance the biological treatment process was being assessed for suitability for a closure site.

All companies interviewed confirmed that there are no dedicated R&D / Demonstration sites that can be used by interested parties to test / verify new solutions (and potentially share the findings with the other potential end users). Central R&D / Demonstration site(s) could help streamline the piloting processes and increase the visibility or, and confidence in, emerging innovative solutions for all mining companies if findings and data are openly accessible.

4.1.5 Innovation implementation into practice (innovation cycle step 5)

The implementation of new solutions is slow. By their own admission, the mining companies are typically not very agile and this, combined with the barriers to innovation discussed below, results in low uptake of innovative solutions and a tendency to fall back on 'tried and tested solutions'. This (they claim) is driven by the fear of not meeting regulatory requirements should a new solution not meet the expected performance criteria over a longer period of time, with different incoming water qualities / quantities and other influencing external factors.

Whilst all of the companies spoken to stated that they have tested many potential solutions over the last five years, very few have been implemented and embedded as 'business as usual' even after successful pilot and demonstration plants have been operated. The range of solutions considered includes:

- **Reverse Osmosis (RO) pre-treatment technology** – trial is almost complete and currently data looks promising. Not yet implemented on site.
- **Membrane technologies** (other than and including RO) – membrane technologies in general have not been accepted previously (including RO, but adoption of this specifically is increasing) so in some cases solutions are being re-explored as more data and case studies have become available. The use of RO to treat mining waters to a potable standard such that local drinking water supplies can be supplemented is being implemented in some areas. Constructed wetlands with membrane bioreactors (MBR) are also being investigated currently.
- **Sorption technologies** – this group of technologies is showing some promise for sorption of contaminants onto biomaterials. This particular example is not yet at the implementation stage.
- **Mine water irrigation** – projects are underway to demonstrate and prove the potential for using treated mine waters for land irrigation. One interviewee noted a project that ran for 5.5 years during which time key stakeholders were all on board with the process. Some 2.5 years after the project took place the team were able to demonstrate that there was still no contamination build up in soils and rivers near the irrigated land were cleaner than before. For the first time, the land occupiers in the project area also reported that they were able to grow a winter crop thanks to the irrigation, which has huge implications for the sustainable creation of local jobs and positive impacts on local economies. The success of this project has led to further roll-outs, including at the Anglo New Vaal site.
- **Freeze crystallisation** – used to recover purified water from the brine solutions resulting from the mine workings. One company interviewed noted that this technology has been tried extensively, but that all trials failed to yield the results required and so the technology has not been implemented beyond a trial / pilot scale.

It was noted during discussions with the mining companies that they felt that there was a general disconnect between the organisations developing the solutions and the relevant academic specialists which led to a reduction in confidence in emerging solutions. It was also commented that more failures than successes were experienced when scaling up solutions.

The researchers, technology developers, and smaller engineering companies that participated in the project provided a contrasting point of view:

- The mining companies could make use of the DSI's R&D tax incentives to decrease the financial risk of testing lower TRL innovations, but even when made aware of the incentives, they do not consider the incentive worth the effort of accessing it.
- Although it has changed in the past 20 years, the true cost of mine water treatment has not been internalised into mine planning and costing at the planning stage. This is why the mines defer action.
- Technology developers and consulting engineers can no longer propose innovations at all without going through a tender process. But this leads to a chicken-and-egg situation: tender specifications for anything novel cannot be developed by the mines unless they know what new ideas are possible. The tender system excludes technical innovation.
- The mines are not well-informed about emerging technologies or know-how because their technical staff are do not have the liberty to attend research events, subscribe to research journals or participate in free forums (e.g. WRC Reference Groups, Coaltech Symposium) without being able to express a clear and quantified business case for spending their time on these activities. Since the benefits of maintaining current knowledge are delayed and indirect, the staff members cannot guarantee a cost saving of X thousand Rands by attending a specific meeting and therefore cannot get permission to attend. In fact, one mining company interviewee commented "our penny-pinching is costing us a fortune".
- Water-related innovation happens in other sectors and then mining catches up.
- Water-related innovation happens in the private sector, and then government catches up (with specific reference to the eWRP, commissioned in the 2000s and then used by the DWS as its reference technology a decade later).

The technology developers and researchers provided a consistent message: the mine water innovation happens outside South Africa and outside the mining industry. Innovations are brought into the South African mining sector when they have already been developed to TRL 9 by another sector and / or in another country.

All of this points to the actual market being close to zero, despite there being ~10,000 sites in the care of ~785 organisations where innovations are urgently needed.

4.2 COMPETITORS AND ROUTES TO MARKET

The mining industry is not an easy place for start-up market entrants. Building strong relationships based on trust with the right individuals within mining and engineering companies is crucial which can be very difficult to establish. Engineers often will not install any new digital technology in a mine site until commercial scale pilots have been run and quantitative data have been proven. Additionally, the mining industry presents many challenging operating conditions which require assets that are very robust and reliable, further adding to the challenges for a market entrant.

There are ~30 large, well-established companies in South Africa providing familiar technologies for water treatment and management to the mining sector (Table 3), with which the start-ups have to compete.

Table 3: Competitors in the water innovations technology provider market in South Africa

Company	Type of provider *	Membrane Systems	Pipes, Pumps, Valves	ZLD	Biological Treatment	Ion Exchange	Chemical Treatment	Thickeners / Dewatering	Metals Recovery
Acciona	SI; EPC	●	●						
AECI Water Group	TP; SI; EPC	●						●	
Aqualia	SI; EPC	●			●	●	●	●	
Aquatech	TP; SI; EPC	●		●	●	●	●	●	
CleanTeq	TP; SI	●		●	●	●			●
Doosan Heavy Industries	TP; SI; EPC	●							
Dupont Water Solutions	TP	●		●		●			●
Evoqua Water Technologies	TP; SI	●			●	●	●	●	
FLSmidth	TP		●				●	●	●
Fluence Corporation	TP; SI	●		●	●	●	●		
IDE Technologies	TP; SI; EPC	●		●					
Kemira	TP						●		
KSB	TP		●						
Metso Outotec	TP; SI	●	●				●	●	
Nafasi Water	TP; SI; EPC	●							
Nalco Water	TP; SI	●					●	●	
NuWater	TP; SI; EPC	●		●					
Osmoflo	TP; SI	●		●					
Pall Corporation	TP	●							
Paques	TP	●			●		●	●	●
Proxa	TP; SI	●		●					
SafBon Water Technology Inc.	TP; SI	●		●	●	●	●	●	
Suez Water Technologies	TP; SI	●		●	●		●		●
Tecroveer	TP; SI			●				●	●
Veolia Water Technologies	TP; SI	●		●	●	●	●	●	●
Weir Group	TP; SI	●	●					●	
WesTech	TP; SI	●	●		●			●	
WSP	SI	●	●	●	●	●	●		●
Xylem	TP; SI	●	●		●			●	

* TP = Technology provider; SI = Systems Integrator; EPC = Engineering, procurement, and construction contractor

The competition landscape is highly fragmented, with no single company dominating: Veolia has the largest market share at 5.9%. Sixteen of the companies in Table 3 account for 1.5-2.9% of the market each.

Foreign large technology providers that try to penetrate the South African market, such as Australian EPC Murray and Roberts, noted that they have not been able to realise as much of a market share as they predicted due to pre-existing strong relationships between mining companies and their preferred engineering service providers, and in the public sector they have not been able to surmount the barriers to procurement from foreign suppliers.

Start-up technology providers, systems integrators and EPCs (e.g. MiWaTek) find it almost impossible to compete with the advertising and business development power of the large companies. Their most promising route to market is therefore through partnerships, intellectual property licensing agreements, or net income sharing with these large companies. Individual start-ups' market shares account for fractions of percentages, if at all.

There are more start-ups for digital solutions, however these usually focus on optimisation of the mining operation itself rather than water management. There have been a few start-ups focussing on innovations to better manage water balance, such as Insight Terra (see more under the "Compact IIoT sensors" subheading of section 4.4.7). The profitability of the digital solution provider start-ups depends on two main features of their business model:

Software *vs* hardware: There is a higher return on investment on software for the supplier; in some cases profit margins can be as high as 80%. However, the market is tiny compared with tangible assets, for which there is a sizeable, growing market for which upper end profit margins are closer to 60%.

Cloud *vs* SCADA: The profitability of a cloud *vs* SCADA solution differs according to CapEx and OpEx. For a cloud solution, there is usually a low initial implementation cost followed by a subscription-based charge. On the other hand, for a SCADA system, there will be a higher upfront CapEx and then a lower ongoing OpEx. The cloud business model is attractive for vendors for several reasons. Firstly, the low upfront cost makes cloud solutions attractive to end-users. Secondly, there is frequently a contract between vendor and end-user for a certain duration, during which, there might be additional income from engineering enhancements, for example. In many cases, enhancements to a cloud system can only be done by the specific cloud solution provider engineers which reduces the risk of competitors taking over. Therefore, in terms of CapEx, supplying a SCADA system is more profitable in the short term however in terms of OpEx, a cloud solution is more profitable long-term.

4.3 FUTURE OPPORTUNITIES

Figure 13 (next page) depicts the key market opportunity areas, splitting the sector into clear segments. Each segment is driven by different needs.

In South Africa, the mining industry is facing the onset of an increasing number of mine closures – in part due to the economic downturn in the commodity sector that forced a lot of mines into earlier-than-planned closure cycles, but also as a natural result of the age of the mining industry in the region. In particular, many of the deeper-level mines in the country are now becoming uneconomic to operate and are slated for decommissioning.

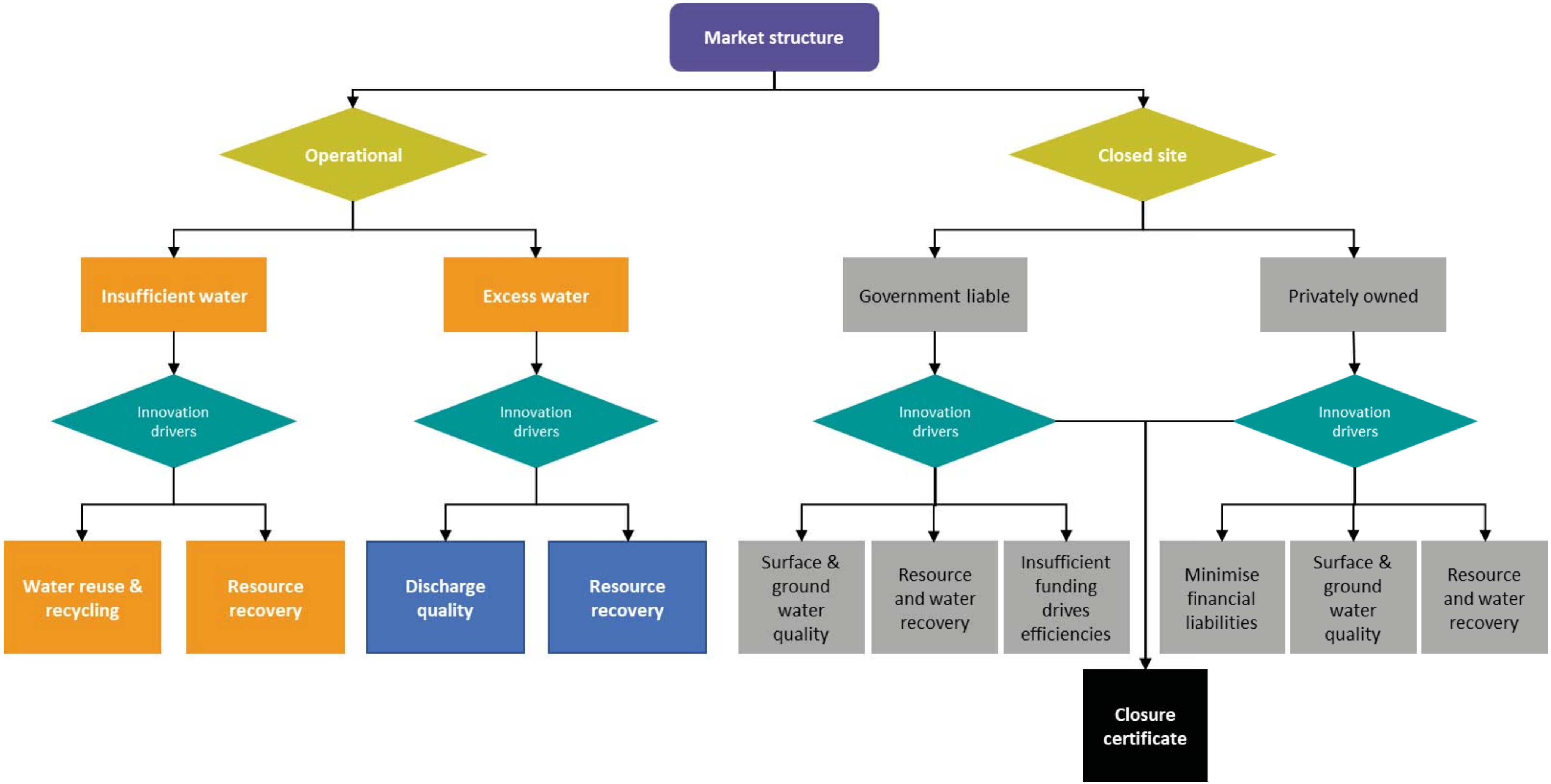

Figure 13: Mining sector market segmentation

One of the market opportunities emerging alongside these closures is the need for ongoing infrastructure maintenance, such as the repair and replacement of pipelines that have corroded or aged. Maintaining above- and below-ground pipelines can be very difficult and expensive, but is often a necessary part of mine closure activities, at times because the site will be inherited by another industry or local authority. There is a significant opportunity here for technologies which allow for easier, cost-effective refurbishment or replacement of pipelines *in situ*.

In South Africa, as well as other regions where power grids may be unreliable or inaccessible, there is an urgent need for cheap, de-centralised power generation technologies. It is essential for continuing operations and risk mitigation that mine sites have reliable sources of power throughout any post-closure activity. There is widespread opportunity for solar-powered water treatment solutions, particularly in remote locations and areas where mines compete for limited municipal power supply. Additionally, there is a lot of interest in using water on-site to generate power, such as through the installation of micro turbines in deep-level, water-positive mines, or adapting existing dam infrastructure for hydroelectricity generation.

4.3.1 Mining sector appetite

The mining companies spoken to all have a good appetite to capture and treat contaminated waters. A number of them also referenced that ‘prevention’ would be better than cure. All companies involved in the interviews depend on RO as one of their main physical treatment technologies, some sites have the capacity to treat 50 megalitres per day (depending on the quality of the incoming waters) to potable standard, others have modular RO plants. The use of RO comes at a high cost (financially and environmentally) though, so particularly where treatment technologies are required at closure sites, other options are always under consideration (subject to the high levels of risk aversion and other barriers discussed below) in preference to RO.

The appetite for technical solutions at closure sites is driven from a different perspective. For all intents and purposes, the waters generated at these sites will need treating in perpetuity, therefore known, trusted solutions such as RO are not financially or environmentally (high energy requirements and disposal of resulting brine discharges) viable. In these closure locations, the appetite is therefore for more passive solutions that can operate for 50-100 years with low costs and no / positive environmental impacts and minimal management requirements.

There are a number of innovation drivers at play.

Regulation: All the companies spoken to (i.e. all sizes and commodities) reported that the regulations they are required to meet are very strict[3], and that they cannot afford to not meet them as all data are publicly reported. In addition, there is a clear reputational impact of not meeting regulatory requirements that the listed and multinational companies are keen to avoid (this however, adds to the risk aversion seen within the very companies with the spending capacity needed to become first adopters of innovations).

Water quality: Regulation dictates the standard of water quality discharge from mining activities. As water quality requirements increase, new solutions are required to meet the more demanding standards.

Green house gas (GHG) emissions: global commitments to reduce GHG emissions is a key driver for innovative treatment solutions in listed companies. Currently, technology developers model the predicted net GHG impacts of their innovations in order to use good GHG performance, the potential to support firm

[3] This was interesting, because it directly contradicts the mining companies’ statement that regulations are not well enforced in South Africa.

environmental objectives, and possible access to carbon tax credits as an incentive for mining firms to implement these innovations. Large multinationals measure their GHG emissions. Non-listed miners do not.

Biodiversity: there is a drive to improve local biodiversity, particularly in the areas directly impacted by mining operations. Treatment solutions that result in positively impacted biodiversity are sought.

Industry associations and NGOs: NGOs and associations are positive influencers with regards to the industry's appetite to explore new solutions and opportunities. The mining companies felt these organisations should be a key source of knowledge exchange and learning, together with being a conduit to details of pre-screened, emerging solutions. Coaltech and the Mine Water Coordinating Body (MWCB) were named as impact partners whose activities lead to broader and faster access to innovations (both water-related and not).

Social Community Plans: The individuals interviewed all felt significant responsibilities towards the local communities in which their mining operations sat. There is a clear desire to reduce negative impacts on these communities and to help make them more resilient and sustainable moving forwards. This was not expressed as a company need, but as a separate, bolted-on topic with an indirect relationship with water with only two exceptions:

(i) Sasol's "outside the factory fence" which consists of offset projects to detect and repair water network leakages, insulate houses, remove solid waste, and test vehicle emissions.
(ii) Anglo American Thermal Coal (now demerged into Thungela Resources) has started a closure plan for its Khwezela colliery based on creating a self-sustaining agri-industrial hub called the "Green Engine". It includes vertical greenhouses using less land and water than traditional farming to produce vegetables and herbs for export, each one employing up to 50 people. They are also investigating producing fit-for-purpose water for traditional irrigated agriculture to grow energy crops, fibre-rich or oil-containing crops.

In recent years, environmental and social governance (ESG) has become increasingly important for mining companies. There is growing pressure from local communities and the extended stakeholder network for mining companies to demonstrate good ESG performance. For example, the investors spoken to are increasingly focused on ESG compliance when making investment decisions, which means that ESG has become a requirement for accessing capital. Mining companies also stated that ESG is important from a marketing perspective, as companies purchasing mined materials to make other products need to demonstrate to the public that their source materials are ethically and sustainably produced. Without good ESG performance and an awareness of both the global and local effects of mining activities, mining companies will not gain a social licence to operate. For multinational miners especially, ESG has therefore become a key factor for staying competitive in the market.

Company obligations / internal standards: a number of the mining companies spoken to referred to standards set internally that in some cases are more stringent than local regulatory requirements. Where their internal standards were more stringent, it was noted that the mining companies in question used the more stringent standard as their goal, therefore further driving their appetite for innovative solutions.

Quantity of water impacted by mining activities: this has significant implications for the cost analysis of the different solutions available to the mining companies and so has an impact on a company's appetite for certain types of solutions.

Cost: costs can be considered as both environmental and financial. Environmental costs have been covered already through the regulatory drivers, financial cost however, is a significant driver for innovation. As with all commercial organisations, budgets are set and agreed on a regular basis. This in turn drives both the appetite and the level of risk to be tolerated. Budgets and cash flow through the businesses spoken to, positively and negatively impacts appetite – reduced budgets drive the desire for cheaper, more efficient and effective solutions, but at the same time it hinders a business's ability to pilot the solution to build confidence in its performance. It appears that this may become a self-limiting factor in the flow of innovative solutions through the mining water sector.

4.3.2 Barriers to innovation by the mining companies

There are numerous real and perceived barriers to innovation within the mining water sector.

4.3.2.1 Risk aversion

Risk aversion is apparent in many activities and behaviours of the mining companies (in relation to water). This risk aversion is driven by a number of complex and interlinked issues, including:

- Limited capital budgets – this impacts an organisation's capacity to trial / pilot solutions. However, without sufficient piloting or demonstration, the mining companies on the whole, remain highly sceptical of potential new solutions. A (mining company) champion of an innovative solution requires a compelling business case and his or her own spending authority within the company to implement trials.
- Fear of not meeting regulatory requirements, resulting in loss of social and corporate reputation, along with the potential to receive fines for missed targets. This further drives the behaviour of 'sticking with the tried and tested' solutions.

4.3.2.2 Regulation

There is indeed a considerable amount of confusion around conflicting or confusing regulations. The relevant regulatory bodies are:

- Department of Water and Sanitation (DWS)
- Department of Environment, Forestry and Fisheries (DEFF)
- Department of Mineral Resources and Energy (DMRE)
- Department of Agriculture, Land Reform and Rural Development (DALRD)

Regulation was quoted as being too stringent by some mining companies, but in some cases not stringent enough. Some of the mines and engineering consultants noted that the multinational miners either choose to comply with the most stringent national regulations they are exposed to across their entire business, OR they do the absolute minimum required on a country-by-country basis and the choice is a matter of mindset rather than available resources, commodity being mined, nation of origin of the company, or any of the factors illustrated in Figure 3: Mining company attributes that determine their level of willingness to implement and / or invest in water innovations.

Mines and consultants stated that where regulations are considered stringent, fear is created around the potential consequences of not meeting the required standards. Equally, if regulations are not stringent enough, the impetus to invest in new solutions is reduced.

Many consultants and regulators shared the view that some mines deliberately overstate the risk of non-compliance as an excuse for not undertaking full scale trials. They are in a position to apply for EIAs and WULA amendments for pilot plants and demonstrations, but do not have the time to await the outcome of the applications, and this is usually because they have deferred their action to mitigate their water risks until the situation has become an emergency. The situation would be greatly improved if government departments provided decisions more quickly and were staffed by people with industrial experience. The majority of consultants sympathised with staff of regulatory bodies who are recently qualified and may be easily deterred from enforcing the rules by site staff with greater age, partly for cultural reasons and partly for longer experience. The Ghanaian EPA was repeatedly offered as an example of a regulator with more confidence and "sharper teeth" but also with the ability to take complex technical decisions pragmatically and thereby enable more extensive, more rapid innovation that led to a better environmental outcome than anything in South Africa.

The consultants and mines are aware of the mines' ability to use the number and misalignment of the many regulations applied to the industry to find loopholes to escape paying fines for non-compliance. They are also aware of the size of the fines and in the event that the cost of taking action exceeds the fine, they will opt to take no action and risk the fine.

4.3.2.3 Lack of dedicated water innovation resources

The mining sectors' R&D budgets are focused on improved production and no other research activity. Examples of successful innovation partnerships and hubs such as the "Future Production: Mining" cluster at the CSIR limit their research focus areas to extraction efficiencies and occupational health and safety. They work primarily on mechanisation and automation. Similarly, Mintek's mining research takes place in its departments of Hydrometallurgy, Advanced Materials, and Biometallurgy.

With one exception, all of the mining companies spoken to had no dedicated resources to identify, review, select, trial and embed new solutions. Most rely on external organisations to provide this service. The WRC was frequently referenced, with particular focus on the value of their historical peer reviewed publications detailing advances in technology. Consultants were also frequently referenced by mines as an excellent source of reputable information regarding new solutions. Only one company spoken to mentioned the role of a newly appointed Project Officer who was having a significant impact on the business' ability to identify and filter potential solutions and accelerate the innovation process in mitigating its water-related risks. Their ambition was to introduce more project officers of this nature to further embed and grow the in-house innovation capability.

4.3.2.4 Lack of supporting evidence

In order for a technology solution to be given detailed consideration, mining companies require robust evidence of technical performance (i.e. the innovation's efficacy and its efficiency compared with conventional technologies or methods that serve the same purpose or perform the same task), together with commercial or full scale case studies verifying past applications. Solution developers aiming to sell into the mining sector need to have clear, well developed business cases that demonstrate an in depth understanding of the mining industry, how their solution compares with competing technologies and what parameters / conditions are required for optimal / claimed performance. Without this level of knowledge and understanding, the mining companies face significant barriers to even justify spending time reviewing a solution, never mind taking it through a trial process and convincing internal governance structures that money and time should be invested into the solution development / trial / deployment.

4.3.2.5 Business / Incentive model

None of the mining companies spoken to could name or point towards an individual business or incentive model that they felt would specifically help accelerate the flow of innovations into the mining sector in South Africa. There was general consensus however on a number of interventions that could support better innovation performance:

- Greater collaboration between all stakeholders (including mining companies, academics, supply chain, associations / NGOs, and government departments) in recognition of the fact that the impacts of the mining processes are not the problem of just one person or organisation, its everyone's problem and we should work together better to solve them faster and more effectively.
- More effective use of industry associations and bodies. The WRC is a highly regarded body, however, it was felt that distribution of knowledge and insight could be improved.
- Greater use of collaborative 'technology showcasing' to raise awareness of what solutions are available. Isle Utilities' iTAG and the ICMM Round Table were quoted as being good at this, together with bringing new people to the table which in turn brings new knowledge and insight to the mix.
- More public funding to support centrally coordinated activities and provide support, resources, and knowledge where it is lacking within the mining company structures.

The British Water Industry has faced very similar challenges to the South African Mining Sector (Water), interview discussions therefore covered the current models being deployed in Britain to accelerate innovation in the water sector to understand how this kind of approach might help. The British model is based on a hub and spoke approach, with a large, publicly funded innovation fund which is awarded (competitively) to the most innovative projects submitted as a mechanism to de-risk innovation, drive behaviour changes around openness and knowledge sharing and to accelerate the uptake of suitable solutions. The funded projects must deliver benefits (short and long term) to the water company customers, society and the environment and push the water companies outside of a 'business as usual' state.

The British water sector requires more cohesion and collaboration if the challenges are to be solved sustainably, therefore, the regulator, Ofwat, has tasked the water companies to develop a Centre of Excellence (or Innovation Hub) to drive and coordinate the sectors innovation activities. This is currently in development, with a sector-wide innovation strategy developed as one of the first outputs of the core working group. Whilst as in the South African mining sector, many of these elements already existed, bringing a formal requirement to the structure with clear roles and responsibilities and defined sector level objectives (from an innovation perspective) is rapidly driving significant change throughout the sector. This model could offer many learning opportunities to the Mining Sector (water) in South Africa.

The financial institutions spoken to commented that the price of potable water is too low and the price of non-potable water is MUCH too low for many – if any – water-related projects to be financially viable in the absence of large national government investment programmes. An additional barrier to investment in water innovations in industry (not only mining) is the historical prohibition of water trading among private sector organisations and the ongoing uncertainty regarding when or whether or how this may change. They expressed frustration with the pace of change, citing the Waste Discharge Charge System (WDCS) and the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) as two examples of how South Africa has ground-breaking ideas but then in the words of two interviewees from banking and consulting, "the ideas are discussed into paralysis".

Two stable funding options already exist for the private sector. First, there is an R&D Tax Incentive administered by the DSI. While some interviewees stated that the R&D Tax Incentive was too burdensome administratively to apply for, others have made full use of it and noted that there are only two forms to completed (one for the DSI and one for the South African Revenue Services) and that they received a 150% deduction of R&D expenditure when determining taxable income.

The R&D Tax Incentive, in boosting "… innovation by improving the capability for developing new products and processes and improving existing ones", provides this tax deduction for expenditure on projects which are aimed at investigative or experimental activities for the purposes of, among others:

- discovering non-obvious scientific or technological knowledge;

- creating or developing an invention as defined in the South African Patents Act;
- creating or developing a functional design as defined in the South African Designs Act;
- creating or developing a computer program as defined in the South African Copyright Act.

The incentive also extends to projects for which the aim is a significant and innovative improvement to inventions, designs or programs. It is open to business of all sizes and in all sectors.

The second funding option is the Climate Finance Facility (CFF), which is a debt facility available to support projects that mitigate or adapt to climate change, including water and energy projects. The CFF is co-funded by the Green Climate Fund and the DBSA, housed under the DBSA, and available to co fund private sector projects in South Africa, eSwatini, Lesotho and Namibia. The CFF addresses risk associated with early adoption of innovations, and difficulties underwriting multiple revenue streams.

The intention of the CFF is to leverage or private sector funding by co-funding alongside developmental and private sector financial institutions to try and achieve a 1:5 leverage. It provide credit facilities for projects which are aimed at:

- Renewable energy generation;
- Energy efficiency in industry;
- Waste to energy;
- Water supply management including water efficiency and treatment;
- Climate resilient water infrastructure.

4.4 OPPORTUNITIES MAPPING

The narrative in sections 3.4 to 4.3 provides the foundation for the opportunities mapped and prioritised in Figure 14, which provides an indication of the criteria used to prioritise the technology choices for water innovation opportunities that would interest potential investors.

All of the technologies listed range across the full spectrum of technology and market readiness. For example, desalination for water reuse can be (and has been) achieved using mature technologies (e.g. standard off-the-shelf RO membranes and conventional brine management ponds) but conversely it can be achieved by uptake of emerging functionalised membranes and brine squeezing technologies that have yet to be applied in South Africa.

Figure 14 indicates that desalination, active MIW treatment, passive ARD treatment, tailings management, safe site closure, monitoring and digital solutions provide clear immediate opportunities. These could be implemented by mining companies and the public sector. Metals and reagents recovery may also have application but would require the materials to be targeted for recovery to be present in the water in sufficient quantities to be financially worth recovering. The reagents would be expected to be used on site and the metals to be processed and added to production outputs.

Each of these technologies is unpacked in the following sections, 4.4.1 to 4.4.7. In order to assess the market readiness level (MRL) of water innovations for the mining sector, we use a combined MRL as seen in Table 10 (Appendix A). The focus of the MRL is to measure the market pull against the technology push associated with technology readiness levels (TRLs). It is therefore strongly based on demand readiness level (Paun, 2012), but with the additional consideration that whichever solution is chosen, it has to fit in its designated environment.

	New mines	Operational mines	Closed mines	Remining dumps
Desalination for water reuse	TRL 9 MRL 9	Only where there is a poor water balance	Where there is excess water and an offtaker	TRL 9 MRL 9
Active MIW treatment	Any site with excess water	Any site with excess water	Where there is excess water and an offtaker	Any site with excess water
Metals recovery (waste beneficiation)		If metals are present in economic quantities		If metals are present in economic quantities
Reagent recovery (waste beneficiation)	If reagents are present in economic quantities	If reagents are present in economic quantities		
Passive AMD and ARD treatment		In the future; should be planned now	TRL ranges from 2 to 9	TRL ranges from 2 to 9
Tailings management	TRL 9 MRL 6	TRL 9 MRL 6	TRL 9 MRL 6	
Closure and site remediation		In the future; should be planned now	TRL 7-9 MRL 3	TRL 7-9 MRL 7
Digital monitoring & management	TRL 9 but opps for innovation; MRL 9	TRL 9 but opps for innovation; MRL 9	TRL 9 but opps for innovation; MRL 9	TRL 9 but opps for innovation; MRL 9

Key:	**Lime green**: opportunity to be targeted immediately	**Amber**: Possible opportunity if conditions are met (e.g. site with poor water balance, either positive or negative)

Figure 14: Opportunities map and decision matrix

4.4.1 Desalination for water reuse

The use of desalination technologies to treat both sourced water and wastewater is becoming more widespread across the industry as miners are forced to rely upon seawater, wastewater, mine water and other brackish water resources for their process water (Figure 15). This trend towards desalination is driven by water scarcity and competition for water resources, as well as regulations which limit the use of preferred water resources. Desalinated or raw seawater is becoming a common alternative to freshwater at many sites globally and can be the sole alternative for an increasing number of mining operations in countries such as Chile, Australia, Namibia, and South Africa.

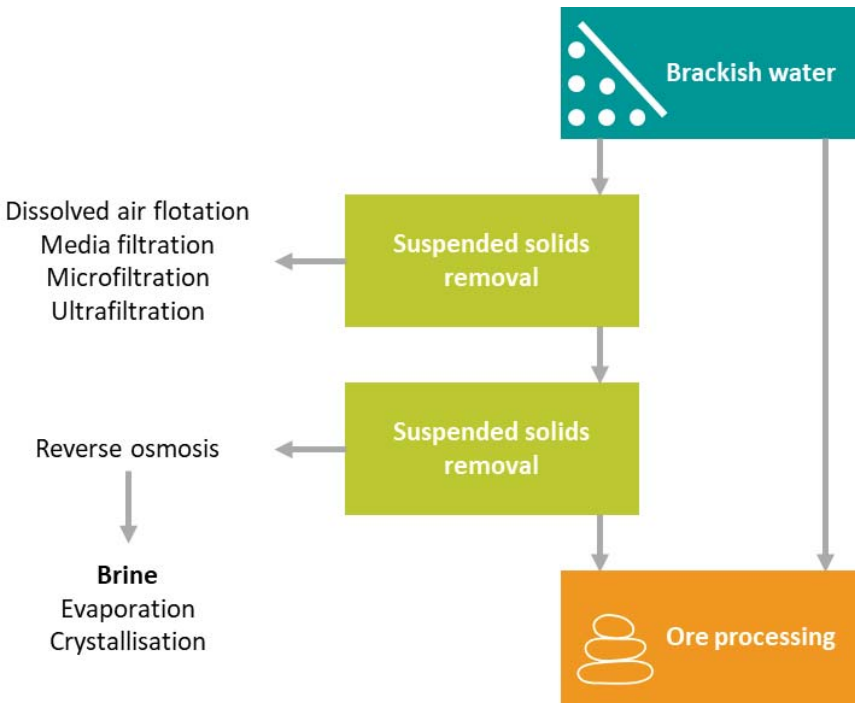

Figure 15: Desalination innovation opportunities in commodity processing

In the face of these restrictions at new mine developments or expansions, the industry will increasingly have to turn to the less-appealing sources of process water which require higher levels of treatment to be suitable for operations. At an inland mine site for instance, the only source of water might be from underground aquifers associated with paleochannels with extremely high salinity, suspended solids, and other contaminants that create challenges for desalination systems.

4.4.1.1 Market readiness

The table below provides an indication of the market readiness level (MRL) as related to desalination for water reuse.

Table 4: MRL for desalination for water reuse

MRL Component	Observation
Supply readiness – availability of technologies	Established in South Africa with several desalination schemes for on-site and off-site water reuse.
Demand readiness – demand for the technology	There is on-site demand at mines with insufficient water for commodity production and off-site demand at mines with excess water that can be treated and sold to off-takers.
Customer readiness – is the sector ready to use the technology?	Customer readiness is limited to active mines with the capacity and capability to build, own and operate desalination plants themselves or engage service providers to do so.
Technology readiness level	Water can be desalinated by biological, chemical, physical and ion exchange processes for active mines. All of these technologies are ready for widespread use.

Therefore the desalination for water reuse segment is seen to be at MRL 9 as the product or service is well defined. The delivery model is clear for the large scale schemes at active mines but there appears to be limited uptake for mines approaching closure or already closed, despite clear potential.

Desalinated water offers the advantage of high-quality water and suitability for all mining applications. The drawbacks include the high start-up costs and associated infrastructure required. In places like Lephalale, the conveyance and energy cost of moving water can significantly increase the total cost of desalination projects, as the mines can be 100+ km away and 2,000 m higher in elevation than the desalination plants.

The improvement of desalination technologies, reduction in membrane costs, and the expense of securing freshwater can make desalination of seawater or brackish water the most economically viable option in many water-scarce regions.

In terms of customer readiness, investment in desalination and reuse declined overall in 2020 / 21, due to effects of the COVID-19 pandemic. Mining companies reduced their CapEx budgets by 12% on average in 2020, which for a major mining company might translate to an overall reduction of R14 billion from a R85 billion to R100 billion budget. Companies primarily producing base metals saw the greatest reduction in their budgets, affecting key desalination technology markets. In addition to the effects of low metals prices, supply chain disruptions, national and regional lockdowns, and outbreaks of COVID-19 at mine sites have caused delays to desalination projects currently underway. There is also an estimated average minimum delay of six months for mining projects not yet underway, as travel restrictions and market disruptions obstruct the planning and tender process.

However, existing projects are not expected to be cancelled outright due to the urgent need for alternative water sources, and planned investments are likely to move forward when metals prices continue to recover, with spending on desalination in the industry projected to pick back up again in 2021 / 22.

4.4.2 Active mining-impacted water treatment

Processing operations can generate large quantities of wastewater which needs to be handled and stored appropriately. This waste stream can be toxic and so needs to be treated, either for reuse within the mining operations or for discharge. In recent years there has been an increased focus on mine water, as discharge regulations for certain contaminants have become stricter. Whilst there are numerous technologies that are able to reach the discharge requirements, these technologies tend to be inefficient and uneconomical.

4.4.2.1 Market readiness

The active MIW treatment segment is seen to be at MRL 7 (Table 5), as the product or service is defined and there is an understanding of who should be planning, designing, and implementing the solution. There are therefore opportunities for novel treatment technologies which can address the following challenges: sulphate removal, total dissolved solids (TDS) removal, and cyanide treatment.

Table 5: MRL for active MIW treatment

MRL Component	Observation
Supply readiness – availability of technologies	Established in South Africa with several treatment technologies for removal of targeted contaminants widely used.
Demand readiness – demand for the technology	There is demand at active mines but although there is a need at closed mines, the need does not translate into a market.
Customer readiness – is the sector ready to use the technology?	Customers see the need but state that the conventional technologies are inefficient and novel technologies are uneconomical.
Technology readiness level	Range from two to nine.

4.4.2.2 Sulphate removal

Although several technologies exist for sulphate removal, the mining companies stated that these are either uneconomical or produce unwanted by-products which require further treatment. Lime neutralisation has traditionally been used, but this no longer meets discharge requirements, which can be as little as 250 mg/L. Reverse osmosis (RO) and nanofiltration (NF) membranes have become popular as the most economical methods for removing sulphates, but both of these create a brine which then needs to be handled. The increased awareness in metal recovery for sulphates is also driving interest in new treatment technologies, including selective ion exchange resins and hydrogen sulphide gas.

4.4.2.3 Total dissolved solids (TDS) removal

Total dissolved solids (TDS) removal was cited as a growing problem for miners for two reasons. The increased use of brackish water in processing means there is more salt in wastewater streams, making it difficult for miners to reach the tightening discharge limits for TDS. Secondly, technologies such as RO produce a brine concentrate, which can no longer be disposed of in tailings ponds, again due to TDS regulations. Several options have been explored for brine treatment, including second and third stage reverse osmosis, which is energy intensive and at a certain TDS level the membranes cannot operate efficiently, as well as evaporation, which is energy intensive, and freeze crystallisation. There will be opportunities for more advanced membranes with higher TDS tolerances, and more economical brine handling and resource recovery technologies.

4.4.2.4 Alternatives to chemical treatment for cyanide

Chemical treatments, such as the International Nickel Company's (INCO) process, are common practice for the treatment of cyanide, which is specifically used in the gold leaching process. Chemical treatments have shown to be reliable, the only downside being the high costs for the transport and storage of the chemicals. Such chemicals are also dangerous to store, a consideration for the health and safety of employees. Some mines are therefore looking into electrochemical technologies, such as electrocoagulation and electro-oxidation, as an alternative.

4.4.3 Resource recovery

Processing waste streams and mining-impacted water contain many valuable resources in addition to water, including residual metals and process chemicals. Many mining companies spoken to are therefore looking for efficient technologies which can separate waste into new revenue streams or recycling opportunities. This can be termed waste beneficiation, values recovery, remining of waste, or resource recovery.

4.4.3.1 Residual metals

Although metal recovery technologies have been growing in popularity for several years, there is still a gap in the market for technologies that can recover residual metals efficiently. High commodity prices act as an incentive to invest in such technologies as this extra revenue stream can offset the cost of more advanced treatment. Another factor which affects the efficiency of metal recovery is water quality, and so miners are increasingly interested in treating process water to a higher quality.

4.4.3.2 Reuse of chemicals

In addition, some of these processes may recover and regenerate spent reagents, which can then be recycled back into the relevant mineral processing step, thereby reducing overall cost of purchasing and transporting fresh reagents.

4.4.3.3 Market readiness

Table 6: MRL for resource recovery

MRL Component	Observation
Supply readiness – availability of technologies	Metal recovery technologies are well established in South Africa with several selective metal removal processes widely used. Chemical / reagent recovery technologies are similarly available but tend to require additional steps after reagent capture.
Demand readiness – demand for the technology	There is demand at active mines and in remining of historical waste dumps.
Customer readiness – is the sector ready to use the technology?	Extensive uptake in the remining segment of the mining sector.
Technology readiness level	Ranges from six to nine.

The table above provides an indication of the MRL as related to recovery of resources (except water). The active resource recovery segment is seen to be at MRL 9. The product or service is well defined, the answer to the expressed need is already built, and there is a solution to solve the problem.

4.4.4 Acid mine drainage (AMD) and acid rock drainage (ARD) treatment

Acid mine drainage (AMD) and acid rock drainage (ARD) are a global issue as almost all mine sites have the potential to produce AMD and / or ARD. It is therefore a priority for mining companies to either find treatment solutions for water already impacted by mining, for discharge or reuse within mining operations, or to prevent AMD and ARD from occurring in the first place. Preventive strategies are the preferred course of action for mining companies as AMD formation is an irreversible process with a long hazard life (millennia), meaning treatment is both ongoing and costly. There are numerous treatment methods in common use for all types of mining-impacted waters, most of which are very well-established (Figure 16) although some miners spoken to felt that some of the methods published in the Global Acid Rock Drainage Guide (GARD Guide, (International Network for Acid Prevention, 2018)) are experimental and still in the research phase.

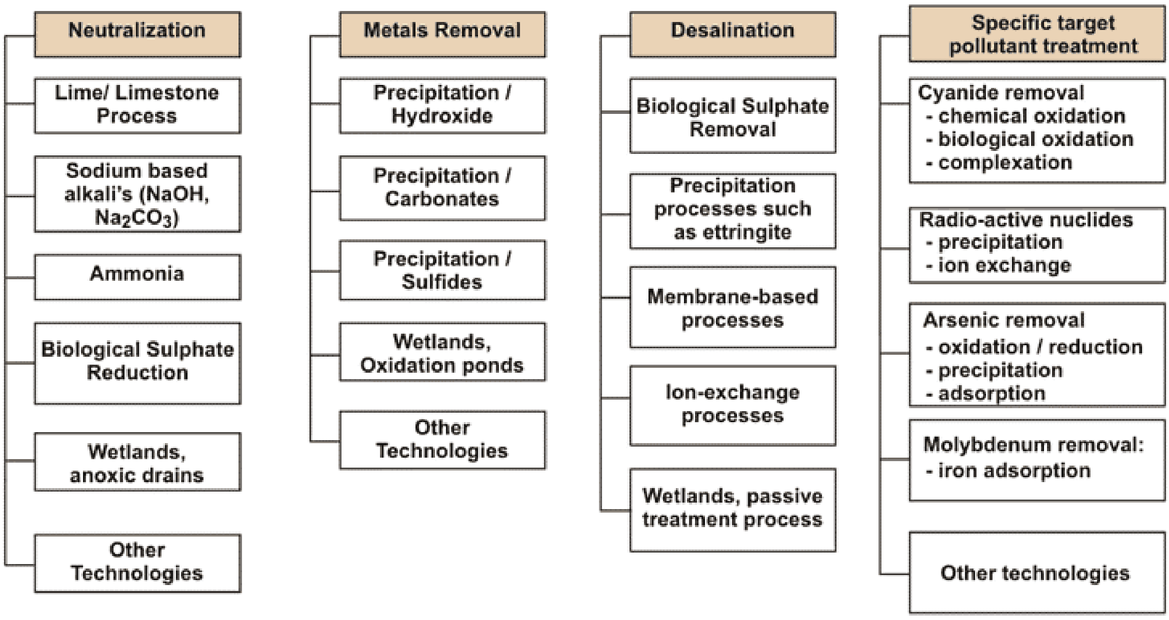

Figure 16: Generic range of drainage treatment technologies (International Network for Acid Prevention, 2018)

Preventive strategies are a common part of initial assessment and designs for mine construction at new sites, but the lack of forward planning at the planning stages of older sites is what has created the legacy issues of uncontrolled discharge of AMD and ARD. Mine water treatment is a necessity but is a grudge purchase so the private sector market is small and driven only by legal obligations and reputational risk mitigation.

4.4.4.1 Controlling pH

Neutralisation technologies are used to address the low pH of water by adding alkaline agents, which neutralise the acid. Lime neutralisation is the most popular neutralisation technology, and also the most popular treatment for AMD in general, due to its proven efficiency and low cost. One of the main issues with the use of lime is the generation of solid waste, which then needs to be managed. The high density sludge (HDS) process is an advanced lime precipitation system, which provides a large reduction in sludge volumes by increasing sludge density; by increasing sludge density from 4% to 20%, the volume of sludge can be reduced by up to 95%. Although innovative technologies are coming to market, many miners and engineers see lime neutralisation as an industry standard, and believe it will be used for many years to come.

4.4.4.2 Removal of sulphide

Metal removal technologies are not standard in mining but are gaining popularity for the treatment of mine impacted water (MIW). Sulphide precipitation processes in particular are used to selectively recover dissolved metals. The benefit of this method is the recovery of high-grade metal products and clean water; whilst metal products can be sold to generate another revenue stream, the water can either be reused within mining operations, or can be discharged into the environment due to its high quality. As regulations for contaminants continue to get stricter, more advanced membrane technologies and ion exchange, are being explored for the removal of specific dissolved solids.

4.4.4.3 Minimising water and oxygen infiltration

The formation of ARD can be prevented within tailings facilities via hydrogeological controls, dry barriers (such as soil, alkaline, organic, or synthetic covers), and water covers. Water covers are the most effective methods for preventing ARD generation, as the concentration of dissolved oxygen in water is approximately 30% less than in the atmosphere. However, water covers can only be used in water positive areas and physically stable areas capable of withstanding extreme weather events.

4.4.4.4 Passive treatment systems

The mining industry has always been interested in passive systems, such as aerobic and anaerobic wetlands, due to their low cost and low maintenance requirements, but their limited capacity and inability to remove metals from mine water itself has been a hindrance for the use of wetlands at large sites. According to the GARD Guide (International Network for Acid Prevention, 2018), most passive treatment projects are treating less than 1000 m^3 a day, demonstrating the low-flow range of these systems. Wetlands remove or retain acid-forming metals through organic processes such as oxidation, plant adsorption, ion exchange with organic matter and precipitation processes under either aerobic or anaerobic conditions.

Passive treatment systems that are almost guaranteed to be effective, that cost very little in terms of CapEx, and that require minimal monitoring and maintenance represent the greatest opportunity, because these types of systems would be applicable to the ~6000 ownerless and derelict mines. These systems would also become applicable to all of the onshore ~4000 mines when they reach the post-closure stage of the mines' life.

4.4.4.5 Market readiness

Table 7: MRL for AMD / ARD treatment

MRL Component	Observation
Supply readiness – availability of technologies	Tens of technologies exist for this purpose but none is ubiquitous. This is partly a function of each closed mine being unique and technically complex and therefore a single technology to apply to all closed mines is not a realistic aim.
Demand readiness – demand for the technology	There is a need at all closed mines and historical waste dumps.
Customer readiness – is the sector ready to use the technology?	The need above does not translate into a market owing to the low spending capacity of government.
Technology readiness level	Ranges from two to nine.

Table 7 indicates of the MRL as related to AMD and ARD treatment. The passive AMD / ARD treatment segment is considered to be at MRL3 because the demand is well defined and the sector is able to identify what the system should do, but there is only a limited number of customers due to the low spending capacity.

4.4.5 Opportunities in tailings management

Tailings dam failures in 2014, 2015 and 2019 have shown that if tailings are not stored properly then dams will fail, causing environmental damage and fatalities. Water is the main source of tailings dam failure, and so it is not surprising that many mines are aiming to minimise the water in their tailings ponds. Over the next five years, the removal of water from tailings dams will be a big opportunity and will drive significant innovation pull. This is supported by the recently released Global Industry Standard on Tailings Management, created by ICMM, UNEP and PRI, which outlines common principles for operators to ensure the safety of tailings facilities around the world. The Standard covers both new and existing mines, and promotes the inclusion of efficient water management practices, the use of new and emerging tailings technologies, and the consistent documentation and monitoring of tailings facilities (ICMM, UNEP and PRI, 2020).

4.4.5.1 Market potential in South Africa

There are three main designs for conventional tailings dams or tailings storage facilities (TSFs):

A **downstream** design (Figure 17) starts with an impervious starter dam, to which tailings are discharged. The embankment is subsequently raised on the downstream slope of the previous section as more tailings are stored. This design was developed for areas with seismic activity and high rainfall.

An **upstream** design (Figure 18) refers to the stacking of trapezoidal embankments from toe to crest, moving the crest further upstream. As tailings are discharged, the tailings next to the dam wall are allowed to drain and dry to form a slurry on which the next section is supported. This drying process takes time and so upstream tailings dams must be raised slowly. This design is suited for areas with low seismic activity and low rainfall.

The **centreline** design (Figure 19) is a combination of both upstream and downstream designs. The crest is in a fixed position and is only raised vertically. Internal drainage can be incorporated to improve stability.

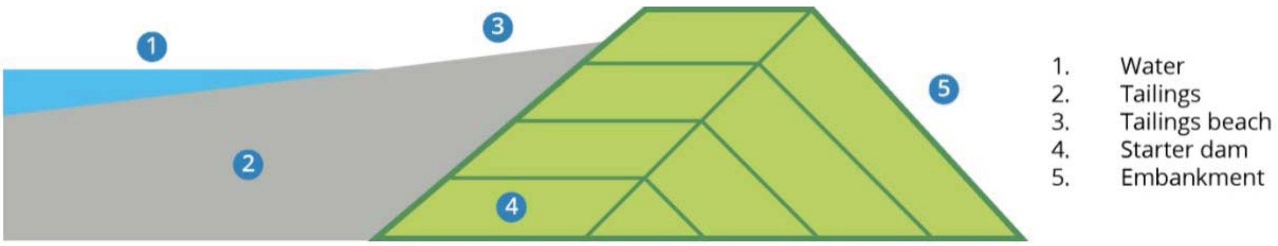

Figure 17: Downstream dam TSF design

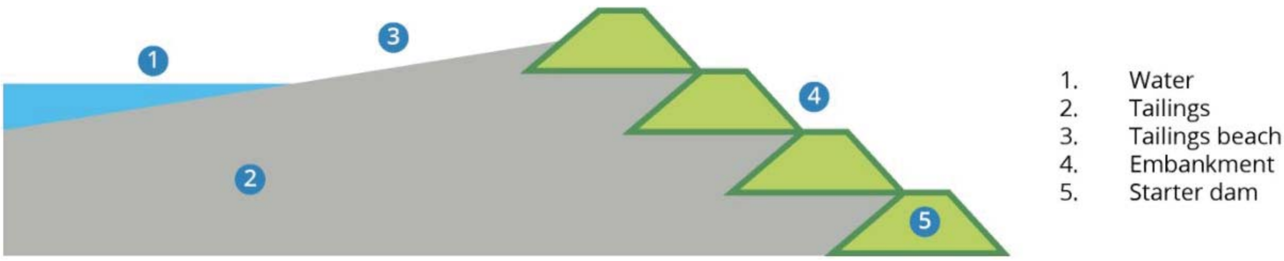

Figure 18: Upstream dam TSF design

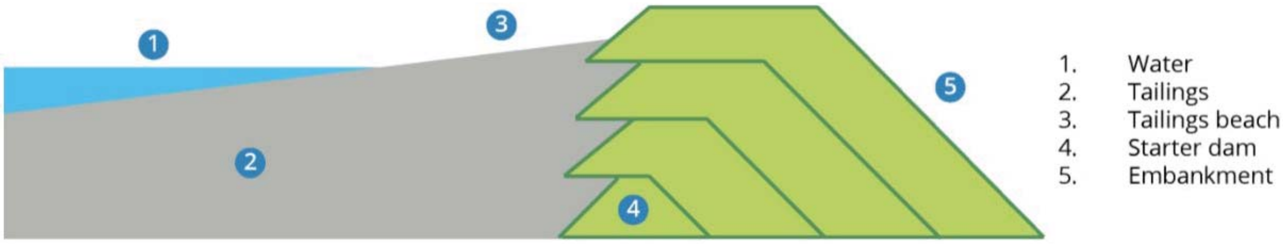

Figure 19: Centreline TSF design

Whilst there is no standard categorisation of tailings sites, the Global Tailings Portal (Young, 2020b) estimates that there are approximately 587 "high risk" dams worldwide, meaning that failure would cause extreme danger to local communities (Figure 20). Although the type of structure built depends on site-specific factors (e.g. topography, rainfall, seismic activity, mineral mined, distance from populated areas, etc.), the safest conventional storage method has been downstream dams, which do not rely on stacking methods.

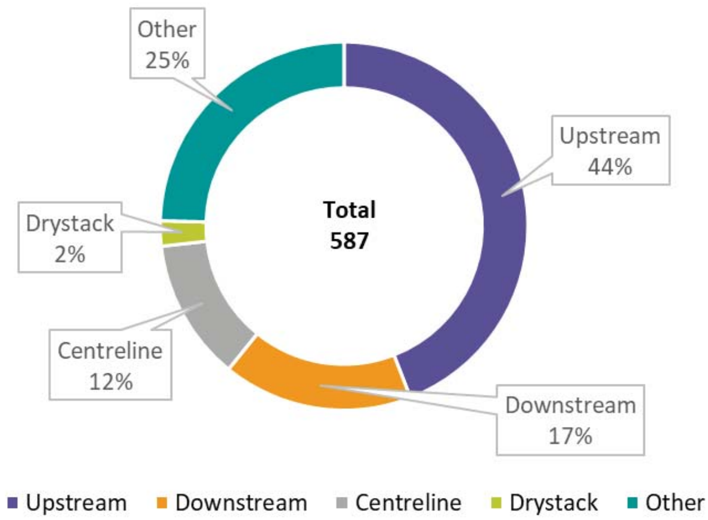

Figure 20: High risk dams by construction type

Downstream dams are the most expensive to construct as they require more construction materials. Upstream dams are of the highest failure risk, with the majority of these located in South Africa (Figure 21). Although the amount of failures is decreasing, the magnitude of these incidents is escalating because of the rapidly increasing volume of tailings being stored, driven by the growing demand for mined materials. It is estimated that there are two tailings incidents per year worldwide. Failure can be caused by numerous factors, including human errors in location, design, construction and maintenance, extreme weather events and earthquakes, structural weaknesses, and water seepage.

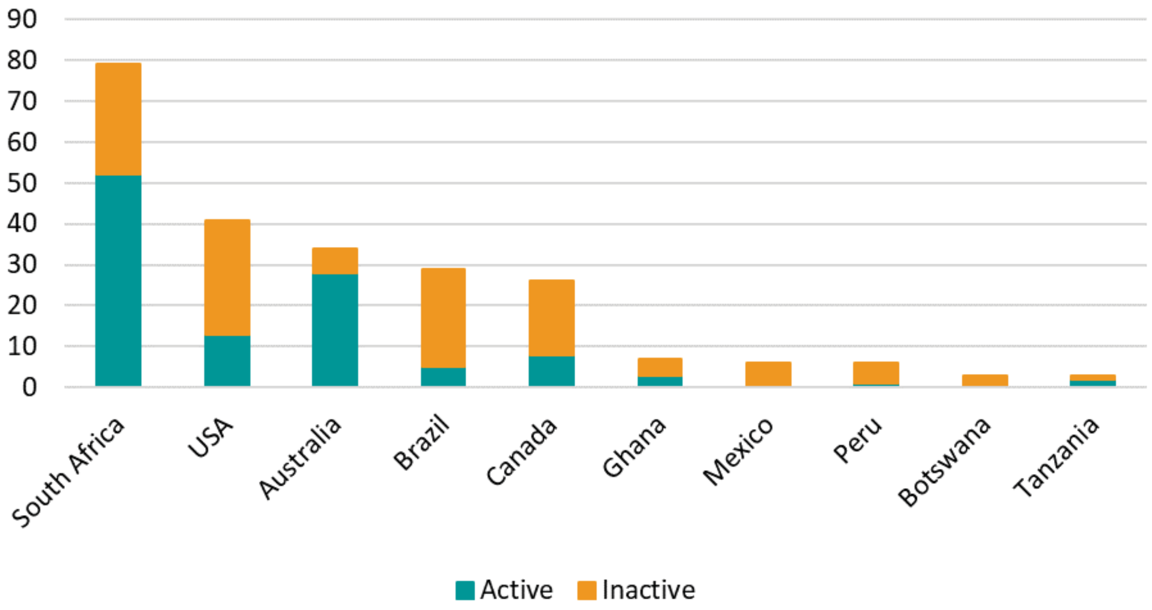

Figure 21: High-risk upstream dams by country (Young, 2020b)

4.4.5.2 Demand for better thickening / dewatering technologies

Reducing the amount of water being released into the tailings dams is the most popular alternative tailings-handling and disposal method, prolonging the life of the dam whilst reducing risk. Conventional tailings typically have 20-60% solids, but these slurries can be dewatered to several different degrees of solidity:

- **High Density Thickened Tailings (HDTT)** will gain popularity in the coming years as regulations for tailings become more stringent. This can be achieved through compression thickeners or a combination of thickeners and filter presses. Thickeners are also the most cost-effective technology for recovering water from tailings streams for reuse in operations and eliminate the cost of transporting and storing water. However, while the uptake of HDTT is a market opportunity, the technologies are already at TRL 9 and this is not the best opportunity for innovation.

- **Paste tailings** have more concentrated solids than HDDT. For example, Kumba Iron Ore stated that an iron ore stream could be thickened to 45-50% solids using HDTT, but when using a paste thickener this increases to 65-70% solids. Although rare due to a lack of proven efficiency, it is expected that paste tailings will become more popular as they require less daily management than conventional storage methods, and can provide high cost savings from water recovery, recovering up to 90-95% of water. Additives such as flocculants and coagulants are added to the tailings feed or thickener to dewater to high densities and paste tailings also require positive displacement pumps for transportation, stimulating markets for low-dose chemicals and energy-efficient, low-maintenance pumps and pump monitors.

- **Dry stack tailings** contain the least water. Tailings filtration systems can generate either wet or dry cakes that produce a stable deposit, referred to as a ‘dry stack’. Like paste tailings, this is a rare method which lacks proof of efficiency in most mining companies’ opinions. There are currently only 66 dry stack tailings worldwide, the majority of which are in Africa. However dry stack tailings have several advantages over conventional storage, by reducing risk of failure due to lack of water, dramatically reducing groundwater contamination, and also allowing better recovery of dissolved metals and process chemicals.

Dry-stack tailings are gaining popularity due to their increased safety. There are currently only 66 dry stack tailings worldwide, the majority of which are in Africa and owned by Anglo American (Figure 22), as they make progress towards a water-less mining system. By using low-cost methods such as course particle flotation, floating particles that are 2-3 times larger than normal, Anglo American has been able to extract more water from the process to be left with a dry, stackable waste stream. Not only does this reduce the risk of failure within the TSF, but it also allows for the recycling of this water within mining operations. Anglo American have also worked with major chemical companies on additives to separate interstitial water from fine metal particles. This system allows for metal particles to be recovered, and also results in dry, stackable tailings.

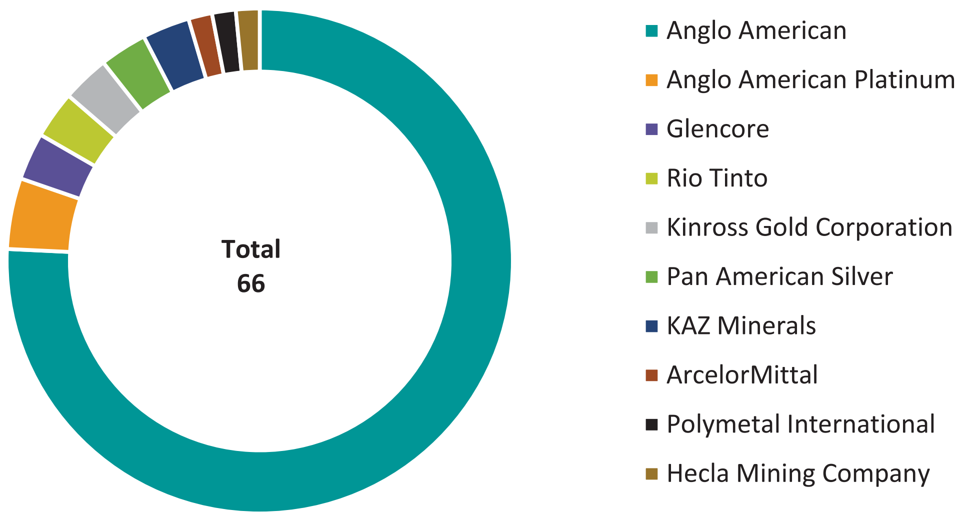

Figure 22: Dry stack tailings by company

As Figure 22 illustrates, eight multinational miners are the second adopters for dry stack TSFs and since they own 1183 tailings dams between them (Figure 23) they represent a strong opportunity for innovation in this application. There are 99 high risk tailings dams in South Africa in total.

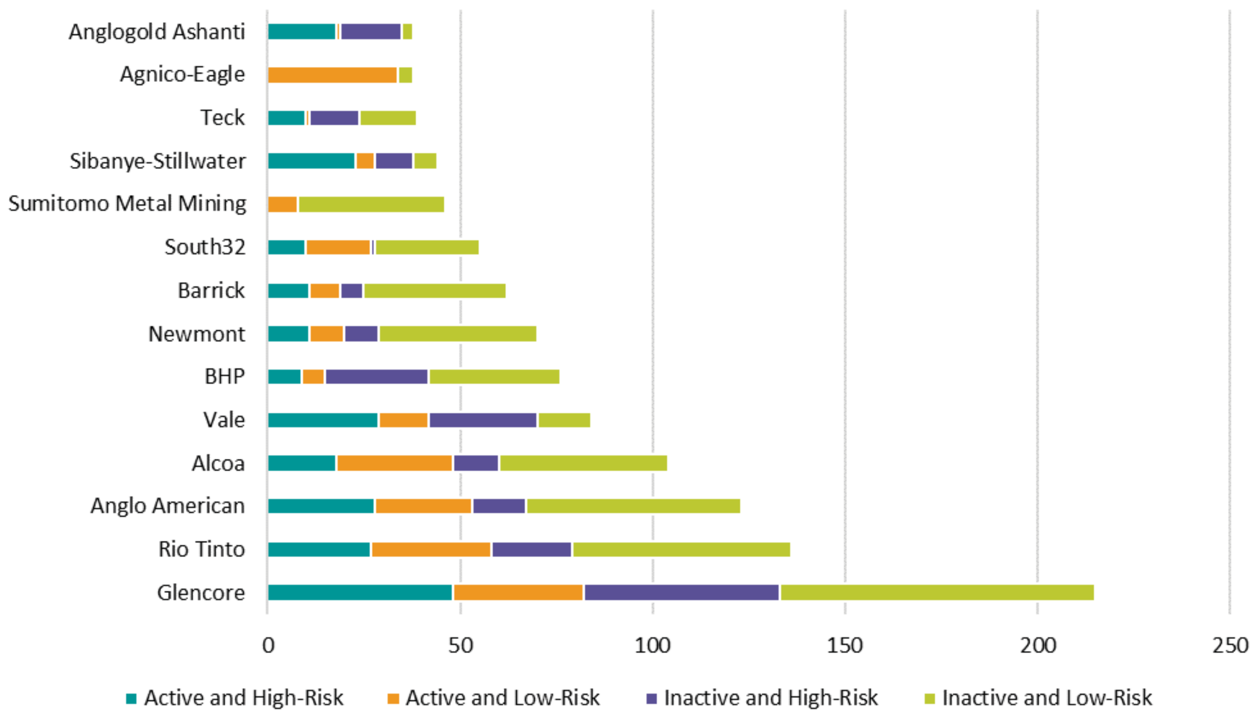

Figure 23: Top fifteen companies with highest number of tailings dams (ICMM, UNEP and PRI, 2020)

4.4.5.3 Efficient methods for metal recovery

Tailings ponds can contain 1-4% of residual metal. When commodity prices are high, this metal can become a revenue stream if separated, offsetting the high costs of the tailings management. This will drive capital spend on dissolved solids separation, such ion exchange resins and UF / NF membrane separation, as well as hydrometallurgical processes such as activated carbon and bioleaching. However, current technologies are not efficient or economical, and so there is a drive for new technologies and processes for resource recovery.

4.4.5.4 Remote monitoring

Mining companies may consider using remote surveillance and real-time data solutions when looking for solutions to tailings management. With the majority of dam failures caused by controllable factors, data-driven insights can help manage safety risks before failure occurs. The mines are already enthusiastic adopters of drones for site surveillance but it should be noted that these were off-the-shelf purchases that required no investment in their development by the mining sector.

We therefore anticipate that although the mining sector is likely to take up remote asset condition monitoring innovations, they are only likely to be open to adopting common practice from other sectors as their new best practice and not likely to be a market for sector-specific innovations in the digital technology space (also see section 4.4.7).

4.4.5.5 Market readiness

Table 8 provides an indication of the MRL as related to tailings management. The TSF segment is seen to be at MRL6. It has been identified on a component level what the system should be comprised of, and the currently available technologies are widely implemented outside South Africa (but only by one customer).

Table 8: MRL for tailings management

MRL Component	Observation
Supply readiness – availability of technologies	There are numerous equipment and engineering service providers that supply this particular market, evinced by the number of commercial consultants offering tailings dam design and monitoring.
Demand readiness – demand for the technology	There is a clear demand for the product as shown in section 4.4.5.1, with a high number of high-risk TSFs in South Africa.
Customer readiness – is the sector ready to use the technology?	This is a challenge as despite the high risk and serious consequences of TSF failure, there has been limited uptake except for one multinational miner (Figure 22).
Technology readiness level	TRL is considered to be 9 (owing to the number of full scale dry stack TSFs in Africa)

4.4.6 Mine closure and site remediation

Though the decommissioning of a mine means it will no longer be producing material, it rarely marks the end of the water treatment and water management activities at the site. Often, water treatment is the largest cost associated with mine closure. The post-closure remediation process aims to ensure – at a minimum – that a mine site is left in a way that poses no environmental or safety hazards, and ideally would return the mine and surrounding area to its pre-development state as much as possible.

The clean-up process varies significantly based on the factors such as type of mine, commodity, location and applicable regulations, lifespan, and mining company standards, but almost always necessitates some activity in water treatment and water management. This can include the removal or stabilisation of tailings, ensuring surface and groundwater flows are unobstructed and unpolluted, and addressing or guarding against AMD and ARD. Mismanagement of the closure process can pose considerable risks to local communities and the environment, sometimes occurring decades after production has ended. The long-term monitoring of a site is therefore necessary to ensure that the mine remains in compliance with local regulations and poses no risks.

When carefully planned and executed, mine closure and site remediation can often be done to a high standard at relatively low cost. But when the full extent of the clean-up is not adequately understood or impending issues are not addressed, a mining company – or government, in some cases – can be saddled with the effort and expense of continuing treatment and maintenance at a site in perpetuity.

The industry framework for mine closure and post-closure is also shifting currently, as miners are forced to assess whether their water management plans for closure and post-closure include not only adequate consideration of environmental requirements, but also the increasing emphasis on sustainability sought by society and many financial backers.

In addition to upcoming mine closures, opportunities exist in remediating abandoned or improperly closed sites which pose a hazard to the surrounding environment and communities, with the cost and liability of these efforts often falling on the national or regional government.

In South Africa, the mining industry is facing the onset of an increasing number of mine closures, in part due to the economic downturn in the commodity sector that forced a lot of mines into earlier-than-planned closure cycles, but also as a natural result of the age of the mining industry. In particular, many of the deeper-level mines in the country are becoming uneconomic to operate and are scheduled for decommissioning.

One of the opportunities emerging alongside these closures is the need for ongoing infrastructure maintenance, such as the repair and replacement of pipelines that have corroded or aged. Maintaining above- and below-ground pipelines can be very difficult and expensive, but is often a necessary part of mine closure activities, at times because the site will be inherited by another industry or local authority. There is a significant opportunity here for technologies which allow for easier, cost-effective refurbishment or replacement of pipelines *in situ*.

In locations where power grids may be unreliable or inaccessible, there is an also an urgent need for cheap, de-centralised power generation technologies. It is essential for continuing operations and risk mitigation that mine sites have reliable sources of power throughout any post-closure activity. There is widespread opportunity for solar-powered water treatment solutions, particularly in remote locations and areas where mines compete for limited municipal power supply. Additionally, there is a lot of interest in using water on site to generate power, such as through the installation of micro turbines in deep-level, water-positive mines, or adapting existing dam infrastructure for hydroelectricity generation. Only Eskom among the interviewees had tested on site power generation through pumped water storage and had not implemented it at full scale, although several of the engineering consultants have been asked by their mining company clients about the possibility of implementation on their sites.

The long-term monitoring of water levels and water quality at closed mines can be difficult and costly, especially at more isolated sites. Installing remote monitoring devices can significantly improve the accuracy of measurements, and replace the need for a person to regularly enter a site to obtain above- and below-ground readings. Miners are also increasingly relying upon systems which collate and analyse data from across a site in order to optimise water treatment and management processes – resulting in cost-savings as well as reducing risks.

Already an essential component of operations across large, closed sites, the COVID-19 pandemic has further spurred interest in communications technologies in the mining sector, as travel restrictions and operational disruptions have limited access to sites. Automated treatment plants and the ability to remotely control technologies are increasingly critical to sustaining operations at both active and closed mine sites.

4.4.6.1 Market readiness

The table below provides an indication of the MRL as related to site closure and rehabilitation.

Table 9: MRL for site closure and rehabilitation

MRL Component	Observation
Supply readiness – availability of technologies	There are numerous service providers offering site assessment and rehabilitation planning and implementation.
Demand readiness – demand for the technology	There is a clear demand because all sites facing closure are legally required to undertake rehabilitation.
Customer readiness – is the sector ready to use the technology?	This is a challenge as despite the legal requirements, almost no mines have been granted closure certificates over the past two decades. Further, site remediation is a grudge purchase.
Technology readiness level	This is considered to be 7-9 as rehabilitated sites are widespread.

The closure and rehabilitation market segment is seen to be at MRL 3. The expected functionality is clearly identified, and the currently available technologies are widely implemented across South Africa and globally, by many customers.

However, there are market opportunities within this segment for lowering the cost of site closure provided that the same outcome can be attained, and the opportunities lie mainly in remote and automated monitoring of water quantity and quality on rehabilitated sites.

4.4.6.2 Monitoring

Water monitoring at mine closures involves measuring both the quality and quantity of water present in order to identify any issues.

Quality: Even after completed remediation activities, long-term monitoring for water quality at a closed mine is essential to ensure the site continues to remain compliant with regulations. Water quality and discharge regulations for closed mines can vary greatly between countries, but common contaminants and challenges for water quality include:

- Acid mine drainage, ARD, and metal leaching
- Nitrogen residues on waste rock from explosives, which may affect surface water quality
- Non-metal leaching – in particular selenium, cyanide, and sulphates
- Excess salinity
- Hydrocarbon contamination

Quantity: Monitoring water levels and flow rates at a site is important for addressing erosion or other instability, tracking stormwater and seasonal runoff, and the early identification of wastewater seepage or leaks.

- Flow rates and water levels are often tracked using meters on discharge pumps, stream velocity measurements, or simple visual inspection. For groundwater levels, either standpipe piezometers or vibrating wire piezometers are typically used; whilst standpipe piezometers allow sampling of the groundwater for water quality measurements, vibrating wire piezometers allow for remote data collection.
- Remote data collection is also gaining popularity for the measurement of surface water levels, including technologies such as automated pressure transducers and radar measurement of water elevation, replacing traditional survey methods and manual readings of water level gauges. This is the application for which several interviewees identified drones as being the latest innovation.

4.4.7 Digital solutions for mine water management

Digital solutions are not limited to closed mines but are becoming increasingly necessary to help mining operators lower OpEx and reduce environmental risk during the active phase of a mine's life.

While mine water management has been one of the last areas of mining operations to embrace digital solutions, there are significant opportunities in this market (Figure 24) especially as mine operators continue to invest more in water-related expenditures. In 2018, spending on water accounted for over 15% of total mining spend (Dean, 2021b).

Digital solutions are increasingly being used in almost all aspects of site management on both active and closed mines, mainly in:

- Integration and predictive modelling
- Advanced groundwater modelling
- Remote dewatering
- Compact IIoT sensors
- Abandoned mines

4.4.7.1 Integration and predictive modelling

It is becoming increasingly beneficial for mining companies to be able to integrate data from multiple different sources into a single big data cloud solution. Aside from water quality and quantity measurements, key data points to integrate include weather, rainfall, reservoir levels and glacier melt for certain regions. Integration of water-related data enables correlations and predictive modelling to be used for mine water management (for more on modelling software see market dynamics). This gives operators control over the desired outcome which reduces risk and helps to ensure that:

- There is enough water for daily operations
- The input water (including reused water) is at the required quality for product formation
- The output water is at the required quality for compliant discharge
- The receiving body of water can handle the predicted volumes
- The status of assets remains optimal

Going forward, there is likely to be increasing opportunity for not just integration of water management data, but also mining operation data as well, particularly from the major mining companies. There are currently data management platforms available on the market that are both standard and customised. While a customised platform might be the preferred option for mining operators, the cost of this is a limiting factor. Examples of large integration and modelling software providers include Innovyze, Schneider, and DHI.

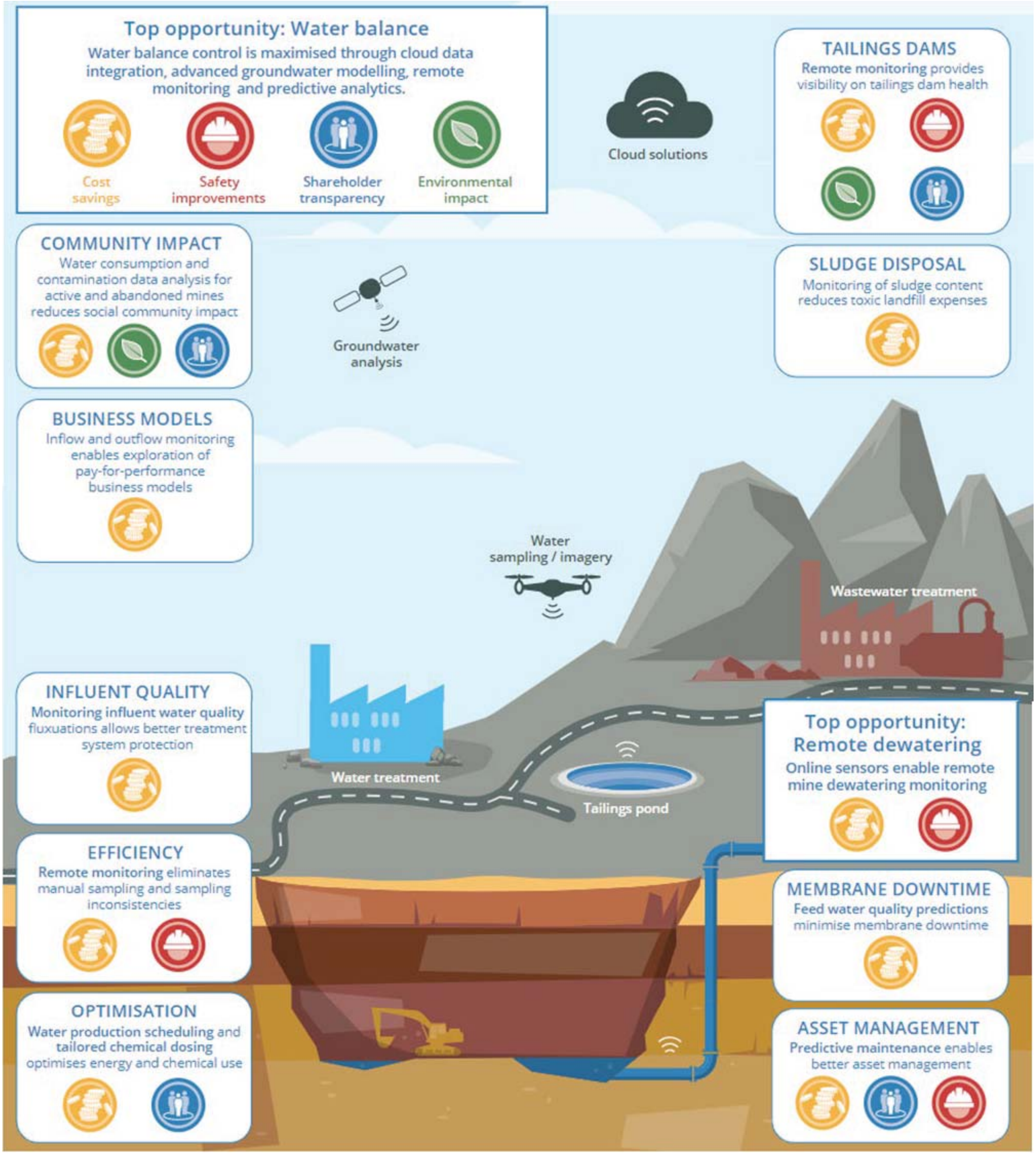

Figure 24: Main applications of digital solutions in the mining sector (Dean, 2021b)

4.4.7.2 Advanced groundwater modelling

Geology is very complex in many parts of the country, which makes groundwater studies and geological modelling particularly beneficial for mine water management in this region (see market dynamics, section 4.4.7.6, for more on modelling software). As mining operators come under increasing pressure to minimise risk, demand for better groundwater modelling will probably be strong. Groundwater modelling enables miners to understand water location, pressure, and volume and helps them select the most appropriate handling methods. In particular, mine dewatering management can be aided through development of 3D numerical groundwater models to indicate groundwater flow. These models are based on 3D geological, structural, and hydrogeological data.

4.4.7.3 Remote dewatering

As the trend for remote operation of mine sites continues, being able to manage mine dewatering remotely is becoming increasingly important, especially in iron ore and coal mines. A monitoring solution including instrumentation is often required in conjunction with a dewatering pump or skid. Measurement requirements include pressure, leakage, flow, and water quality. Remote monitoring ensures continuous operation, reduces operator exposure to the mine and saves operator time as well. Going forward this is an opportunity that is likely to grow, particularly as large new projects continue to come online, for example in the Waterberg.

Building up trust with mine operators is crucial for development of this opportunity. Convincing mining operators of the reliability of sensors and automation for dewatering can be difficult.

4.4.7.4 Compact IIoT sensors

As it becomes increasingly important to reduce power consumption and the cost of hardware, there is an opportunity for low powered compact industrial internet of things (IIoT) sensor systems. Traditionally, in remote areas of a mine, a digital monitoring solution consists of a battery pack and transmitter as well as the individual instrumentation. However, instrumentation suppliers are now starting to produce very low power compact sensors with an integrated gateway which eliminates the need for a separate transmitter and battery pack. These can then communicate directly to an IIoT or cellular network, possibly 5G in the future. For example, Endress+Hauser has recently released a new IIoT-enabled level sensor with an integrated gateway which is able to communicate directly with the IIoT network.

4.4.7.5 Ownerless and derelict mines

There are abandoned mines all over the world, including Australia (estimated at around 60,000), the USA (around 500,000), Latin America and to a smaller degree, Europe. However, the biggest drive for digital solutions implementation is likely to be in the USA, due to the scale of the problem, increased allocated funding and pressure from the Biden administration (Parker, 2021). The South African market opportunity for digital solutions on closed mines will remain small unless there is a disruptive legal intervention similar to the current changes in the USA.

The US EPA is placing increasing emphasis on cleaning up these mines. For example, in July 2020, the US Congress passed the RECLAIM Act (pending Senate approval), which will disburse US$1 billion over the next five years to clean up abandoned mines and restore watersheds. In September 2020, the US EPA launched the Office of Mountain, Deserts and Plains aiming to effectively address abandoned mines. Providing remote water quality monitoring systems, particularly for metals, excess salinity and acidity will prove increasingly important to ensure that the treatment system installed at the abandoned mine is working properly and that the surrounding groundwater is at the required quality and not adversely impacting the environment.

4.4.7.6 Digital market dynamics

There is a need for digitisation of water management in mining. However, due to the conservative nature of the industry, the adoption of new advancements can be a very slow process. It will take some mine sites many years before they fully embrace digital solutions for water management. Many of the larger and more profitable mines have implemented digital systems for multiple aspects of the mining operations however water has generally been the last area to which digitisation is applied.

As more opportunities open up for data integration and predictive modelling, use of modelling software is becoming increasingly important. Examples of commonly used modelling software include GoldSim, MATLAB

Simulink, The Geochemists Workbench, PHREEQC and Stella Architect. GoldSim, for example, is a probabilistic simulation tool well known for creating mine water balance and quality models which can be used for risk analysis, environmental impact studies, strategic planning, and resource management. This simulation relies on a model of an existing / proposed system allowing it to understand controlling variables and then predict future system behaviour.

As stakeholder transparency is a key driver of digital solutions, simulation platforms that are easy to understand and enable real-time model experimentation (e.g. enables operators to respond to stakeholder questions in real-time) will be highly beneficial for mine operators (Dean, 2021b; Parker, 2021).

While in the past, reliability of sensors was a limiting factor for remote monitoring at mine sites, newer sensors and more attention to sample preparation has reduced this limitation. There are three key steps used to ensure reliability:

- **Sample preparation**: Extracting the contaminant(s) of concern from the mining effluent ensures that the highly polluted effluent is kept away from the analyser and does not destroy it. This is a process that can be done remotely and autonomously.
- **Sensor regeneration**: To prevent operators from having to clean the sensor manually, which takes up valuable operator time and effort, there are sensors available that are able to constantly regenerate and renew on the surface. For example, Aqua Metrology Systems (AMS) provide sensors that are able to do this.
- **Continuous calibration and validation**: Continuous online remote calibration and validation of sensors is crucial to ensuring reliability.

It is becoming increasingly common for end-users to go to one equipment supplier and ask for a package solution rather than using the services of a consulting engineering firm and assessing the marketplace. This is particularly common for smaller mining companies.

There is a growing trend in trying to use satellite frequency technology to be able to create imagery which can be used for analysis. This can then be combined with advanced machine learning and artificial intelligence to assess the water quality of a specific area.

A lot of operators still have manual sampling systems. Being able to provide self-powered packages integrating a low-cost sensor is commonly required, particularly for tailings dams. The most common measuring parameters required are turbidity, pH, conductivity, and level. With this the instrument supplier will most likely supply a transmitter and gateway as well as a solar panel and battery to allow this information to be fed back to the operator's SCADA system using telemetry at older sites, or the cloud and WiFi at newer ones. The level measurement is to ensure the dam does not overflow and the quality measurement is to ensure the water is compliant if being discharged, or meeting specifications if being re-used in the process.

Traditionally in the mining industry, asset management has been employed for the most valuable components in the production operation, such as a US$2 billion mill, for example. However, it is becoming increasingly requested for smaller components with a much lower value, including those within the water sector of the mining operations. In mine water management, asset management is particularly important for pipelines, storage tanks, pumps, valves, steel tanks, any rotating equipment, filtration, and flotation. Managing leaks in pipelines, in particular, is very important. The most common structural problems in mine site water come from pumps, pipes, and filtration devices.

Asset management is particularly beneficial for a mine site water management because the overall operating cost of this management is much higher than in most other industries meaning OpEx savings are significant. There are three key ways in which asset health management can save mine operators OpEx:

- **Planned maintenance**: Being able to predict failures in hardware enables planned maintenance which is always cheaper than unplanned, both due to labour costs as well as parts and maintenance.
- **Preventing unplanned downtime**: Ensuring downtime is minimised. There is more value on the processing or operational side as opposed to water however unplanned downtime can still significantly impact mine water management. For example, if a pump suddenly fails in a slurry pipeline, the solids content might jump from 50% to 80% because there is not enough water entering, which could block up the pipe. Fixing this pipe could be costly and also result in production loss.
- **Extend asset lifetime**: Monitoring assets enables preventative maintenance to be carried out and pressure on individual assets to be controlled. This helps to extend asset lifetime.

At the large mines, there has been a strong focus on asset management in the last three or four years. This is due to the current stage of the expansion cycle. Around 8-10 years ago, miners were more focussed on expanding and less concerned about operating costs. However now investors are pushing mine operators to get the most out of existing mines rather than expanding and decreasing operating costs is crucial for this.

For smaller and medium sized mines, convincing them of the benefits of asset management is harder. Providing quantitative data using real case examples on the benefits that asset management offer will help drive uptake in smaller and medium sized mines.

4.4.7.7 Emerging digital technologies

There are a few emerging digital technologies for water treatment in mining. The key drivers for these are device simplification, cost reduction, eliminating unnecessary hardware and reducing the need for manual sampling.

- **Satellite technology**: Remote sensing satellites with both visible and thermal bands are particularly useful for tailings management. Water imbalance, which can arise from a number of climate variables such as rain, run-off, snow, snow melt and evaporation, can have a big impact on tailings storage facilities. Using satellite data such as topography, land use, rainfall accumulation, flood detections and surface energy, enables more accurate flood models to be made and provides support for mining operators to improve climate change risk management.

  Using satellite and high-resolution drone imagery across large portions of remote land also enables assessments to be made about the surrounding ecosystem, which can indicate level of impact from mining operations. Areas of concern can then be more thoroughly investigated through ground analysis.

  There are many companies offering remote satellite sensing to the mining industry such as Satellite Applications Catapult, Exploration Mapping Group and Geoimage, to name a few.

- **Radar analysis at abandoned coal mines**: The University of Nottingham has recently developed a remote monitoring tool using satellite radar imagery that captures millimetre-scale measurements of changes in terrain height. An advanced Interferometric Synthetic Aperture Radar (InSAR) technique, called Intermittent Small Baseline Subset (ISBAS) developed by the University of Nottingham and its spin-out company Terra Motion Ltd., can then be applied to the radar satellite images. This can be used to monitor and forecast groundwater levels as well as geological changes below the earth's surface at abandoned mines. This technique was implemented at Nottinghamshire coalfields (abandoned as recently as 2015) in the UK.

- **Drones**: Using drones has become more common in other mining operations outside of water. For example, they can be used to quickly reach areas trucks cannot for surveillance and data collection and those with cameras can take images and videos of certain areas. However, drones can be useful for mine water management too, especially those with embedded sensors or attached water sampling equipment. Attaching water sampling equipment to a drone enables it to gather water from the surface, transitional and deep layers of mine pit lakes. This reduces risks associated with operator exposure and saves time.

  Drones with the ability to carry out thermal infrared imagery have also been used to assess groundwater-surface water interactions at mining development sites. However, there are downsides to using drones for this kind of surveillance instead of helicopters. The aerial coverage is often smaller, the time taken for the survey is longer due to the lower ground speed and depending on region, there can be regulatory barriers that must be met before flying the drones as well.

- **Mine water sampling radio-frequency identification (RFID)** uses radio frequency to enable tracking of tags across long distances making it ideal for mine water sample tracking. Using manual water sample labelling is time consuming and can result in errors and inconsistencies. However, equipping water sample bottles with RFID tagging would enable sampling information, such as location and date, to be stored and then downloaded in the lab.

  While this would be beneficial for mining operators, opportunity for uptake in this is likely to become less over the next few years as online sensors / meters take the place of traditional manual sampling.

- **Laboratory on a chip technology**: There is opportunity in the market for portable devices which can detect heavy metals and pollutants in water at ultra-low concentrations, otherwise known as 'laboratory-on-a-chip' technology. Developments are being made in this area. For example, French market entrant, Klearia, has developed PANDa, a device able to do this that provides real-time responses. While PANDa has so far been tested largely for drinking water purposes, investigation into mining application is underway.

- **Ground penetrating radar (GPR)**: Using GPR to be able to look at water levels and compounds within the water, such as metals, which can replace the need for manual readings, is a growing trend in the market. Providers of this include IDS GeoRadar and MALÅ GPR Australia.

- **Compact IIoT sensors**: Sensors that can reduce power consumption and necessary hardware are becoming more common in the market.

4.4.7.8 Market readiness

The table below provides an indication of the MRL as related to digital solutions.

This is seen to be at MRL 9 as there has been widescale commercial application and the product has been clearly defined. There has been interest for implementing the technology at selected sites but it appears that the customer readiness component of the market does need to be addressed.

Table 10: MRL for digital solutions

MRL Component	Observation
Supply readiness – availability of technologies	Technologies are available in other sectors and are developing rapidly but are not as widely available in South Africa as in some other mining countries (e.g. Australia, USA).
Demand readiness – demand for the technology	There is a clear demand at all sites for water quantity monitoring as a minimum requirement.
Customer readiness – is the sector ready to use the technology?	It would appear that is a challenge as despite high potential there has been limited uptake in the South African mining sector.
Technology readiness level	There are many mature and off-the-shelf technologies being widely used in sectors apart from mining, and also in the mining sector but not yet for water management: TRL 9.

CHAPTER 5: MARKET FORECASTS

Sections 5.2 and 5.3 contain five-year forecasts broken down into total market and type of infrastructure for water transport and treatment; assessed by purpose of innovation; and finally a detailed assessment of the most promising sub-market, which is digitalisation. The forecast methodology is described in Appendix C.

Internationally, the market for water innovations in mining is cyclical and driven by supply and demand. In the usual business cycle, demand pushes prices up, and supply increases to try to capture that windfall, sending prices down again. In a supercycle, supply is so inadequate to demand growth that prices rise for years, even a decade or more. The market is currently within the first few years of a supercycle, but this has been impacted by the current COVID-19 pandemic (Clarke, 2020).

With China accounting for a large part of demand for South African mined commodities, a recovery in the Chinese market is the most influential global factor on the mining sector. Europe and the USA were easing out of lockdown at the time of writing (July 2021) and those markets appear to be recovering, but a global recession is predicted by agencies such as Moody's and S&P Global.

According to S&P Global, the coronavirus crisis is expected to push total global mining exploration budgets 29% lower overall by the end of 2021, with Australia and Canada to be the hardest hit countries. A lot of South African exploration activities are dependent on junior mining companies, which are unlikely to be given financial support over the next year. S&P Global have predicted that actual mine site exploration will only reach ~40% of licence allocations (Innes and Cairns, 2021).

5.1 INFLUENCE OF RELATED SECTORS

The global and South African markets for water innovations in mining are driven primarily by five factors in related sectors (a, b and c are expanded upon in section 5.4):

a) Demand for an electrified future of electric vehicles (EVs) and electronic devices;
b) The clean energy revolution and increased use of renewable energy sources;
c) Increasing emphasis on ESG and social licence;
d) Industrial growth in China;
e) The predicted USA-China trade war.

China accounts for the largest demand of South African ferrochrome metals due to Chinese industrialisation, which is still in its infancy and therefore strong, with a predicted 30 years of steady demand ahead. China is the top importer of iron ore; 98% of world supply is used for making steel, largely for the construction industry. Bauxite is also strongly tied to Chinese industrialisation, as it is used for the production of aluminium. While impacted by the COVID-19 pandemic in the first half of 2020, growth in China is now back on a growth path.

The trade war between the USA and China has already affected the international market for rare earth metals. Rare earth metals are in demand as they are used for magnets in high-end technologies such as the automotive and renewable energy industries. China is the top producer, generating 77% of global production in 2019, making South Africa and the rest of the world reliant on Chinese exports. However, tightening environmental regulations in China and industry consolidation are providing opportunities in other countries, including South Africa, which have potential to provide rare earth commodities.

Therefore despite the short-term COVID-19 market conditions, the long-term trends in the mining industry are as follows. They have been calculated based on known figures for 2016-2020 and projected based on the drivers and restraints described in sections 5.4 and 5.5 respectively.

The increased use of renewable energy will drive the production of copper, nickel, and zinc (Figure 25). Whilst copper and nickel are both used in numerous technologies, zinc production will be driven by the increased use of wind power, as it is used to coat turbines against corrosion.

	Wind	Solar photo-voltaic	Concentrated solar power	Hydro	Geothermal	Energy storage	Nuclear	Carbon capture and storage
Aluminium	●	●				●	●	
Chromium	●			●	●	●	●	●
Cobalt						●		●
Copper	●	●	●	●	●	●	●	●
Graphite						●		
Indium		●					●	
Iron	●					●		
Lead	●	●		●		●	●	
Lithium						●		
Manganese	●			●	●	●		●
Molybdenum	●	●		●	●		●	●
Neodymium	●							
Nickel	●	●		●	●	●	●	●
Silver		●	●				●	
Titanium				●	●		●	
Vanadium						●	●	
Zinc	●	●		●		●	●	

Figure 25: Mapping minerals with relevant renewable energy / low-carbon energy industries

An increase in Li-ion battery consumption is expected to be driven by the increased popularity of electric vehicles (EVs) and electronic devices, and so has become an important driver for many base metals, including copper, nickel, cobalt, and lithium. Whilst copper and nickel are used within various other industries, cobalt and lithium are almost primarily used in Li-ion battery production. Copper demand is expected to increase by 50% within the next 20 years, according to The World Bank. The increase in the copper price should drive spending in the copper mining segment, and the increase in demand should drive an increase in commercial interest in remining copper wastes including tailings.

5.2 WATER TREATMENT

Total CapEx in South Africa on water management and treatment was R18.2 billion in 2019, and R149 billion globally. Based on a South African share of between 11.7% and 12.2% of the global market over the past five years and an anticipated slower economic recovery than the USA, Canada, and Australia (owing to a slower vaccination roll-out immediately post-pandemic), we have assumed a depressed share of the market with international total growth outpacing South African growth over the 2021-2026 period (Figure 26).

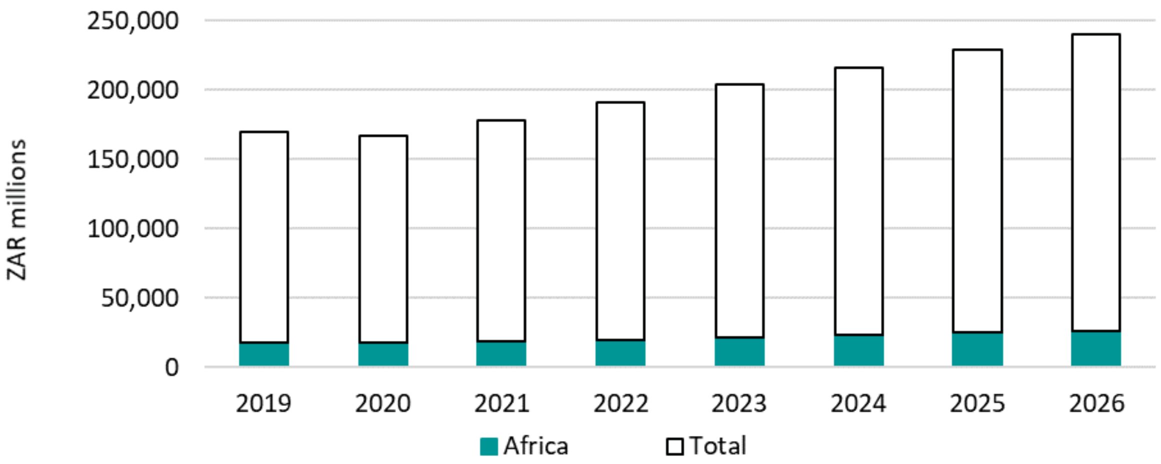

Figure 26: Mining sector CapEx on water management and treatment in total (2019-2020 actual; 2021-2026 forecast)

The market for water-related infrastructure and water treatment (Figure 27) takes decreasing access to continuous supplies of suitable quality water for commodity processing into account alongside the locations of most of South Africa's new mines in dry areas (Section 3.3.4). Even mines with positive and neutral water balances will be pushed towards on-site water reuse and recycling between now and 2030.

Figure 27: Predicted mining sector market for water-related infrastructure and water treatment (2019-2020 actual; 2021-2026 forecast)

Most of the treatment technologies used in the mining industry are basic, and suspended solids removal technologies accounted for over half of spending in 2016-2020, with most of this going towards clarifiers. Given the risk aversion of the sector that was evident from all of the interviews, regardless of the type of stakeholder spoken to, we do not predict that the market for innovative treatment technologies will grow unless deep and sweeping regulatory changes are implemented and consistently enforced.

Mine sites are not usually constrained by space and system footprint, so there is little drive for more compact technologies. More advanced technologies will find their niche where there is a specific need, such as the use of RO in seawater desalination in water scarce mining areas, the use of biological treatment for the removal of certain elements from wastewater, or the use of NF and RO for treatment and reuse of water in tailings dams. These advanced technologies are not innovative; they are all well-established technologies at TRL 9 and the fact that many mining company interviewees regarded them as innovations reveals their lack of access to research outputs and new knowledge.

Mining sector expenditure on water treatment technologies declined overall in 2020 due to the coronavirus pandemic, which has impacted the mining industry and delayed investment in new projects and planned upgrades (Figure 28). Spending is expected to rebound in 2021-2022 as the economy recovers, therefore we have used 2019 rather than 2020 as the baseline, and forecast the market to grow steadily over the next five years. The majority of investment will remain to be in fluid handling and the scope for innovation there is restricted to digital and remote asset management and improving energy efficiency rather than to disruptive means of moving fluids.

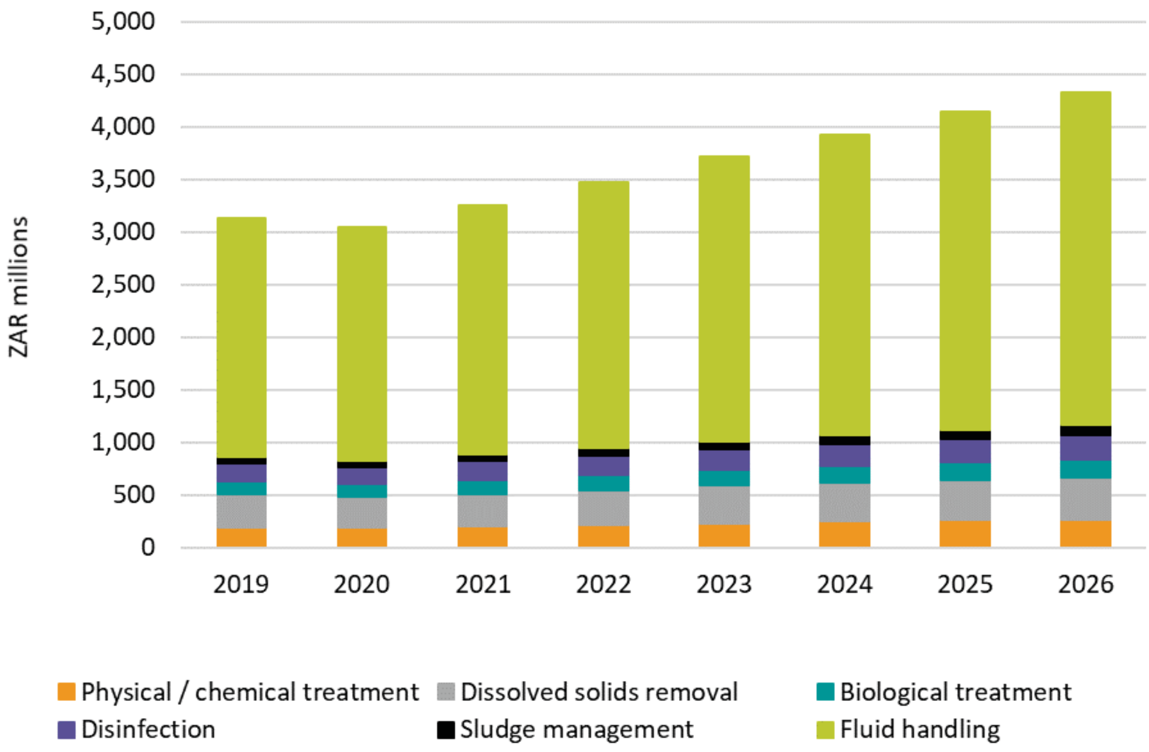

Figure 28: South African market size by purpose of innovation (2019-2020 actual; 2021-2026 forecast)

5.3 DIGITALISATION

This digital forecast is built on a model that divides spending on data collection, control and monitoring, and data management and analytics solutions in the water sector between different categories, including product types, applications, and parameters. The model estimates the percentage of total spending that is directed towards these solutions in different utility and industrial sectors, and then how this spending is split between these categories.

The starting point for our model is our estimates of total water-related spending in each sector, which are derived from the Global Water Market forecast (Dean, 2021b, 2021a). We then estimated the percentage of total spending that will be directed to digital solutions in each sector. This percentage was informed by interviews with industry experts, information from individual projects, and estimates that we have made about the unit cost of different components.

5.3.1 Spending by category and application of technology

Spending for online sensors / meters (physical and water quality) takes up the biggest proportion of this market (Figure 29) and growth is expected to remain strong (Figure 30), especially as online sensors and meters are continuing to take the place of lab and field testing. COVID-19 accelerated a pre-existing growth of digitalisation in 2020 / 21 with the need for remote monitoring being more important than ever before, meaning investment in instrumentation for on-site monitoring is increasingly being prioritised by mining companies and site rehabilitation and monitoring companies. Online sensors / meters are more efficient, require lower OpEx, and are more accurate than lab / field testing and avoid the problems associated with interprovincial travel during lockdowns. Since investment in digital systems involves CapEx, we expect that mining will not revert to previous monitoring methods after the pandemic. Supply of online instrumentation for remote dewatering and abandoned mines will therefore present opportunities, as will the need for compact low powered IIoT sensor systems.

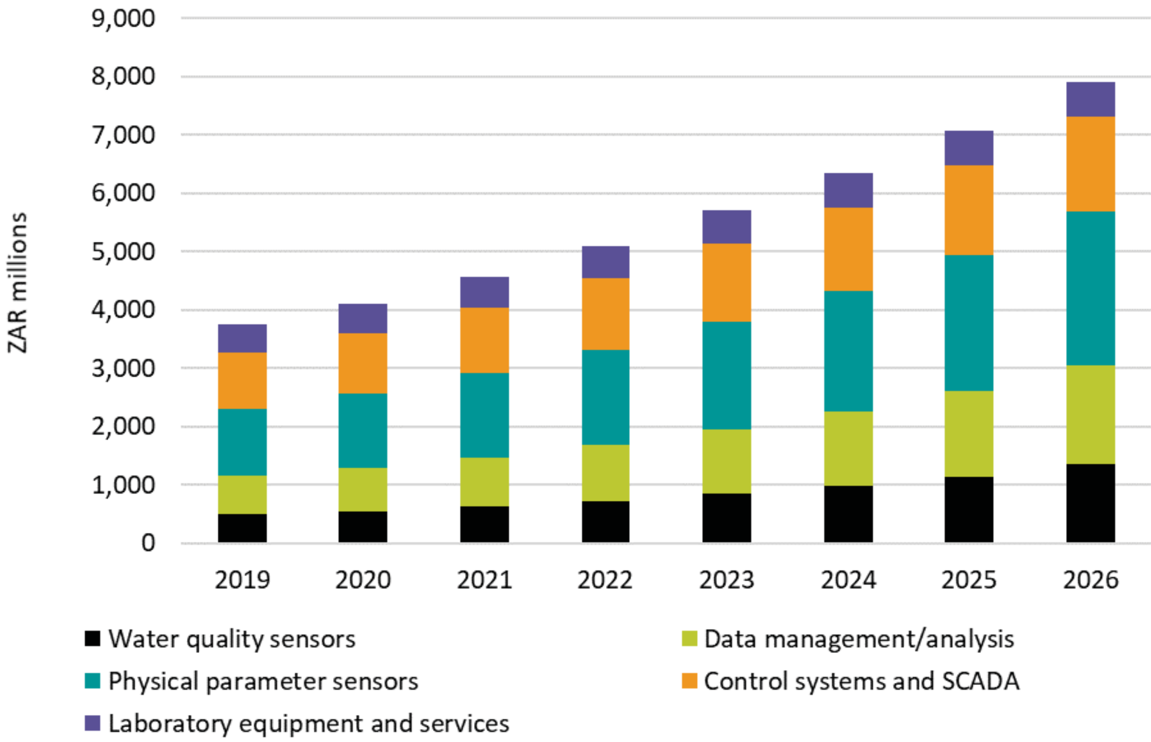

Figure 29: Previous (2019 / 20) and forecast (2021-2026) total spending on digital solutions, by category

Growth in data management / analysis is also likely to be strong as operators are increasingly looking to integrate data into cloud solutions and improve water balance management through sophisticated predictive modelling (see top opportunities for more). Spending in automation and control is likely to experience slower growth as a lot of mining sites already have existing control systems, such as SCADA, which can have additional items incorporated into them. Cloud solutions are expected to experience faster growth than SCADA systems.

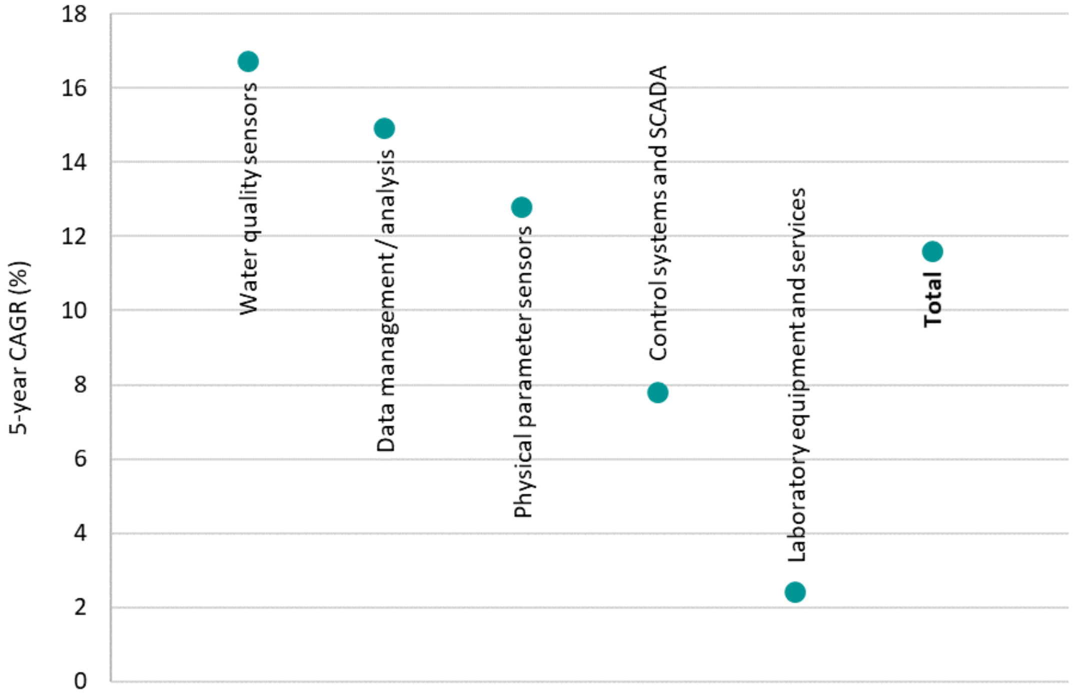

Figure 30: Compound annual growth rate (CAGR) by category

Definitions of categories in Figure 29 and applications in Figure 31 can be found in Appendix C.

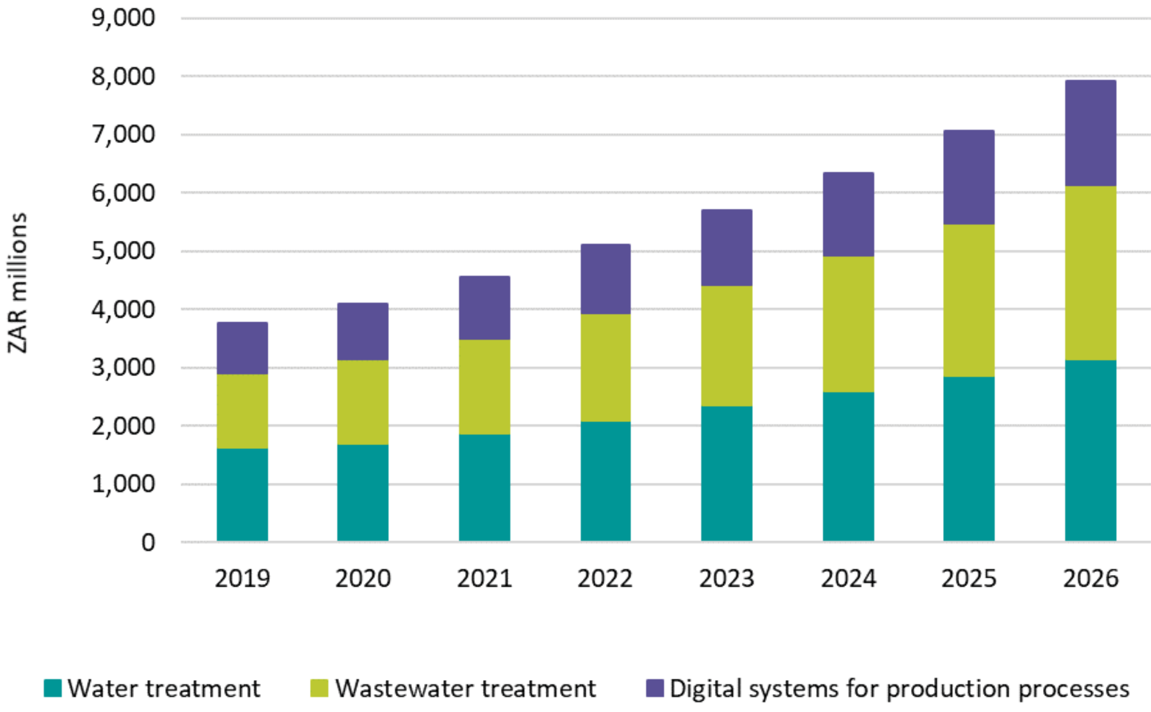

Figure 31: Previous (2019 / 20) and forecast (2021-2026) total spending by application

Spend per customer: Depending on the size and complexity of the mine as well as how far along it is in the digitisation process, CapEx will typically be between R700,000 and R3 million for a digital site monitoring system. The majority of this spend will be on the instrumentation with software being primarily OpEx. An average of R70,000-R145,000 per instrument is likely.

5.3.2 Spending by type of parameter

While a larger proportion of the market is taken up by physical parameters, growth in spending on water quality sensors is expected to be faster than physical parameters sensors. The sensors forecast (black bars in Figure 29) can be further broken down into types of sensors for different parameters (Figure 32). The biggest drivers for increased uptake in water quality sensors / meters are increasingly stringent regulations, limiting social community impact and increasing shareholder transparency.

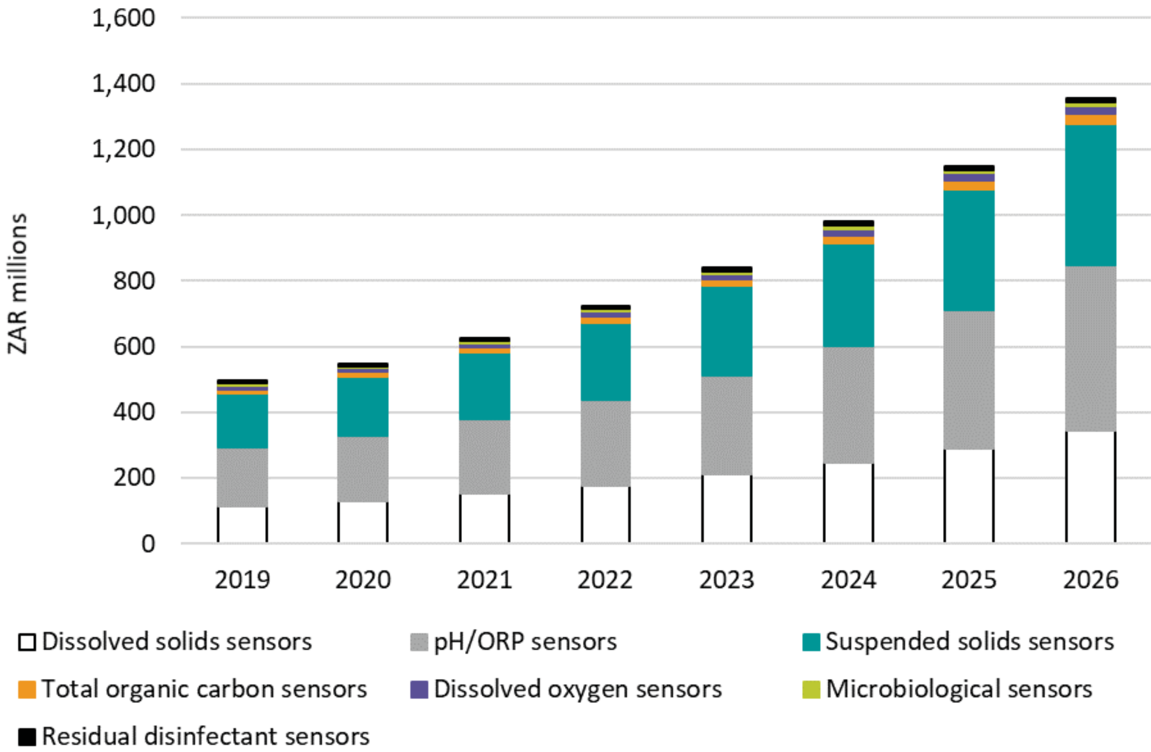

Figure 32: Previous (2019 / 20) and forecast (2021-2026) spending by parameter

The largest proportion of water quality CapEx goes to dissolved solids, suspended solids and pH on account of the most common water quality measuring parameters in mining being turbidity, conductivity, and pH. Monitoring of abandoned mines will also drive growth in spending on water quality analysers, particularly for metals, acidity, and excess salinity.

5.3.3 Data management / analysis – further insight

Cloud solutions: Cloud solutions are becoming increasingly in demand, and as such, uptake is growing at a faster rate than for SCADA systems. There are several advantages for the end-user of cloud systems over SCADA. Firstly, a cloud solution is cheaper to implement, with little or no upfront capital cost. Secondly, engineering does not have to be done by a specialised control system provider meaning maintenance and upkeep for a cloud solution is easier. Thirdly, it is easily scalable enabling replication for multiple facilities.

Asset management: Traditionally in the mining sector, asset management has been employed for the most valuable components in the operation, such as a US$2-billion mill, for example. However, it is becoming increasingly requested for smaller components with a much lower value, including those within the water sector of the mining operations. In mine water management, asset management is particularly important for pipelines, storage tanks, pumps, valves, steel tanks, any rotating equipment, filtration, and flotation. Managing leaks in pipelines, in particular, is very important. The most common structural problems in mine site water come from pumps, pipes, and filtration devices.

Value proposition: Investing in digital solutions for water management at a mine site can result in significant operational savings for the mining companies. For every R1 installed, there is the potential for an operator to on average, get at least R4 or R5 back in savings. For an average sizeable mine, a monitoring system can save at least R7.2 million per year in water management operational savings. Monitoring systems also enable mining operators to avoid regulatory fines through precise analysis and certification of what is in the water, wastewater, and sludge.

5.4 DRIVERS

5.4.1 High commodity prices

High commodity prices drive capital spend on both new and existing projects. When commodity prices are high, there is a corresponding increase in mining activity and new developments, driving big-ticket CapEx projects as well as increased OpEx for water treatment. At existing projects, miners are more willing to consider investing in new treatment technologies, particularly those that are more advanced or innovative. For example, miners may upgrade their systems to recover metals more efficiently from waste streams, as the additional revenue will now offset the investment cost.

5.4.2 Competition for a secure source water supply

From an operational standpoint, companies are being / will be impacted by climate change and the implications this poses on the availability of water for onsite processes. So not only will high quality discharge waters be likely required, but there will be a growing need to reduce and reuse water in process operations.

With 80-90% of new mines built in water-scarce areas, miners are increasingly competing against municipalities and agricultural users for fresh water. Environmental permits are becoming more difficult to obtain in areas where the water resources have already been fully allocated unless it can be demonstrated that water withdrawal levels will be near zero, or that communities will not be adversely impacted. Miners are consequently seeking alternative source for process water, driving the market for desalination technologies for wastewater and mining-impacted water and other reuse technologies or know-how where fresh water for mining is very restricted.

Water scarcity affects around 50-60% of mines, with many mines operating in arid regions. Therefore, reusing water is an opportunity for innovation. The quality of water that can be used within mining operations is likely to be lower than discharge quality, meaning that less treatment is needed, if any. However water must still be fit-for-purpose, which is dependent on the process it is used for; for example, cyanide leaching for gold requires high quality water for the chemical reaction to occur, whilst processes such as copper flotation and oxide leaching do not require high quality water. This limits the pull for innovation for water reuse.

It is unlikely that mines will be able to reuse 100% of their water, as around 10-20% of water cannot be controlled due to weather-events, evaporation, and pipeline leaks. According to ICMM, mines committed to water reuse are recycling an average of 60% of their water and some companies such as Anglo American, by using a closed loop recycling system and advanced evaporation measurement technology, had reached rates of >75% water reuse in 2019, covering two thirds of their operational water requirements and limiting their interest in further advancing water reuse technology or know-how. The water reuse innovation market is not the multinationals leading in the water stewardship arena, but the junior miners who are the second adopters of innovations.

5.4.3 Tightening discharge regulations

Regulations governing environmental discharge are becoming more stringent locally and across the globe, pushing miners to optimise or upgrade their wastewater treatment systems. Traditional technologies are increasingly unable to keep pace with these restrictions, driving market growth for more advanced treatment.

Government level commitments outside of the mining sector, including their commitment to be waste free (i.e. nothing going to landfill) by 2022, whilst seemingly unachievable to date, will drive the need to improve production and process efficiencies so that more resources are recovered and reused.

As environmental regulatory standards become more stringent; the demand for socially responsible companies increases, and the need to financially account for remediation activities post closure grows, demand for new solutions is anticipated to grow.

On 1st June 2021, the recently revised financial provision for rehabilitation and mine closure came into force through which companies are required to create cash deposits (values determined through set calculation formula) to cover the costs of:

- Rehabilitation upon premature closure
- Decommissioning and final closure
- Post closure management.

All companies have one year to comply. Communities are held as central priorities to benefit from these funds, therefore there is likely to be an increased appetite to find sustainable solutions to the challenges faced, and to facilitate the maximum positive impacts of the funds set aside by each company, which blurs the line between this and the following driver, ESG.

5.4.4 Growing commitment to ESG

Part of good ESG performance is the demonstration of good water management. There is no “one-size-fits-all” approach for water usage and wastewater treatment, as each mine site faces different water-related challenges depending on its location. However, a more holistic approach to good ESG performance is the increasing focus on transparent reporting, which is encouraged by a number of voluntary standards, such as the Initiative for Responsible Mining (IRMA), the International Council on Mining & Metals (ICMM), and the Extractive Industries Transparency Initiative (EITI). Many multinational and larger local mining companies have set challenging water sustainability goals to demonstrate their commitment to limiting water usage and increasing water recycling within operations. For example, Anglo American has installed new technology to measure evaporation rates and are exploring dewatering technologies for dry tailings disposal, in order to increase water efficiency with a closed loop recycling system. Glencore has constructed an RO treatment plant at one site, reducing their freshwater withdrawals by 1.6 billion litres a year, and in Chile, it has replaced its sprinklers with a drip irrigation system to minimise evaporation rates at this water scarce site. Such actions will provide positive attention for the both the individual company and the mining industry as a whole, thereby helping provide a social license to operate.

5.4.5 Lower grade ores

As global demand for mined materials has increased in recent years, the easier-to-mine resources have been largely depleted, necessitating a pivot to sulphide-heavy ores and coal to keep production levels up. The extraction process for these lower-grade ores requires higher amounts of water and chemicals – generating larger, more polluted mine water streams which are more costly to treat and manage. Additionally, the higher sulphide content of tailings from these resources coupled with stricter discharge standards has driven increased spend across key regions as miners scramble to remain compliant.

5.4.6 Tailings management

The recent failures of the tailings facilities at Brumadinho (Brazil, 2019), Samarco (Brazil, 2015) and Mount Polley (Canada, 2014), and the catastrophic effects these have had on both the environment and local communities, are driving mining companies to invest in new water management methods and treatment technologies. With excess water identified as the main culprit for most tailings dam failures, there has been an international push to minimise the water in tailings ponds. Over the next 10 years, adoption of new industry best-practice standards will drive investment in water management solutions and treatment technologies, particularly relating to ZLD and reuse, as well as chemical solutions such as thickeners.

5.5 RESTRAINTS

5.5.1 Low commodity prices

Most commodity prices have been negatively affected, with base metals bearing the brunt of the pandemic with a 6-8% reduction in price, due to a lack of construction projects globally. Precious metals have seen less of an impact, with gold holding a “safe haven” status (Young, 2020a).

At lower commodity prices, mining companies decrease or postpone production, thereby delaying investments in both new and existing projects. This has a negative impact on opportunities for water innovations as mining companies are not willing to invest in sites mining low-priced commodities. With less mining activity, less water is being used, and so existing frameworks are likely to cope with the quantity of water processed.

5.5.2 Low water prices and access to capital

South Africa’s water tariff is lower than the actual cost of treatment of complex water sources, including MIW. The engagement of institutional investors such as pension funds and insurance companies in water infrastructure is therefore limited. Commercial banks can be attracted by low-return but low-risk water investments in developed countries but will be less attracted by similar projects in developing countries, where risks are higher. Commercial risk arises when the revenues from the service are lower than required, either because the service is not appropriately charged, or the willingness to pay is too low (Leflaive, 2016).

International Financing Institutions (IFIs) often accept lower returns than commercial banks but offer commercial terms in middle-income countries including South Africa. More and more countries, notably middle-income countries, find it is easier to finance their infrastructure needs in private capital markets (e.g. bonds are gaining traction), rather than with loans from IFIs, due to the conditions IFIs set.

5.5.3 Funding and procurement mechanisms

The South African public sector procurement process is uniquely restrictive in several ways. Bid evaluation follows what is known as the 90-10 rule. That is to say that the components of price and soft issues are weighted at 90% and 10% respectively. While there are no official prequalification criteria in the procurement process, the 10% made up by soft issues is crucial as it involves aspects such as a bidder’s B-BBEE compliance. The preferential procurement policies govern contracts and tenders where national and provincial government bodies are involved. These policies therefore apply to the majority of water and wastewater projects where mining companies are working with their local or district municipalities (Filou, 2020).

Public-private partnerships (PPPs) are regulated through various legislations: the PFMA, the PPP Manual and Standardized PPP Provisions (which are issued as Treasury Practice notes under the PFMA) and the Municipal Finance Management Act (MFMA). South Africa also has a central PPP Unit, the Government Technical Advisory Centre (GTAC), which advises and supports the Treasury on major infrastructure procurement, including PPP.

The legislative framework is meant to cut across the various levels of government (municipal, provincial, and national), but in practice, it works best at national government. At subnational level, especially municipal, PPP-related texts overlap and contradict other legislation: for instance, the MFMA and the Municipal Systems Act both require feasibility studies for a PPP, but with different scopes. Stakeholders have also noted great variations in PPP support between municipalities and provinces. In general, it was felt that dedicated legislation is required for PPP to take off at sub-national level.

5.5.4 Conservative industry approach

Mine sites have typically not required advanced water treatment, relying on large ponds and conventional treatment methods imported from other sectors. Whilst mining companies are looking for new or alternative ways to cut costs and maximise efficiency, they are wary of investing in unproven technologies given the potential financial and environmental risks, particularly if installation requires production down-time. Mining companies prefer to see proof of large-scale, real-world testing to demonstrate efficacy – a requirement which makes it difficult for new technologies to gain a foothold in the market. For this reason, technologies developed by well-established, globally recognised companies in the mining sector are likely to have an advantage over start-ups and research organisations (universities, science councils, etc.).

The powerful role of conservative consultants is generally considered to hamper the introduction of new and innovative technologies.

5.5.5 Lack of technical knowledge

Non-major mining companies can lack the in-house skills to understand the water treatment technologies available, as well as operating the water treatment facilities. As a result, the uptake of advanced technologies, even those which are mainstream in other sectors such as membrane technologies or zero liquid discharge (ZLD), may remain limited.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The major conclusions that can be drawn from this research are as follows:

a) There is a profound disconnect between the need for water innovations and the current market. Although there are up to ~11,000 sites with urgent needs for effective water management and / or treatment technologies and know-how, there are only five to ten customers for water innovations that have real spending capacity, plus the appetite to use it.

b) The potential market is thousands of mines in private and public hands. Some legal reform is required to unlock the market, but mainly stronger enforcement of existing legal frameworks.

c) The closure certification requirements imposed by the DMRE are so ambitious that the sector will not even attempt to meet them (stated by interviewees as being a requirement to reduce mitigated risk to zero). Only two site closure certificates have been issued in the past 20 years, although the total number of applications is not clear.

d) All the market opportunities are onshore. There are two offshore sites and they are in the diamond extraction industry, the most secretive commodity segment of the market.

6.2 RECOMMENDATIONS

6.2.1 Policy

The South African market will remain small unless there is a disruptive legal intervention, beginning with

[1] strict enforcement of current legislation, moving to

[2] realignment of currently contradictory legal requirements issued by the DMRE, DWS and DEA, and finally

[3] consolidating water-related regulatory responsibilities within a single department,

thereby closing the loopholes through which the sector is currently able to “mom-and-pop” national government.

In parallel, the country needs to address ownerless and abandoned mines as a matter of urgency. Doing so would require two main policy adjustments: an adequate budgetary allocation to implement the regional mine closure strategies already drawn up by the CGS on behalf of the DMRE, and the capacity for the implementing department to expedite implementation under the existing emergency procurement provision made in the National Treasury regulations.

The regulatory bodies need to be capacitated by filling vacancies through recruitment of personnel with experience in the mining sector, to upskill the public sector workforce by importing practical knowledge about what is possible and the experience to challenge mining companies with knowledge and confidence.

6.2.1.1 Stronger and more consistent enforcement of existing regulations

Regulations drive uptake of innovations that can help operators ensure they are remaining compliant. However in a lot of cases, the extent to which regulations are enforced is limited. The impact of regulations on uptake of innovations significantly varies from country to country. Aside from water, regulations regarding air quality monitoring, particularly CO_2 emissions, are likely to become stricter over the next few years. Carbon taxation is in place and should be used alongside water-related regulations to drive a whole-system reduction of environmental impacts.

One example of successful regulatory drivers from other countries is the case of Canadian coal mine contaminants in the USA: The US government became increasingly concerned about high levels of British Columbian coal mine contaminants ending up transboundary water. Consequently, there is increasing pressure from both USA and Canadian authorities to improve water quality. For example, in September 2019, the US EPA produced a report linking British Columbia's Elk Valley coal mines with high levels of selenium downstream in the state of Montana. Towards the end of 2020, Environment and Climate Change Canada issued a directive under the Fisheries Act to a British Columbian mining company, Teck Resources, setting out requirements for water management which included diversions, mine planning, fish monitoring and calcite prevention measures. Going forward there is likely to be increasing pressure placed on Canadian mining companies to better monitor and control effluent which creates opportunities for remote monitoring instrumentation and related data management software.

6.2.1.2 Stronger promotion of existing incentives and alignment with regulation

Regulations governing water discharged to the receiving environment are becoming more stringent across the globe, pushing miners to optimise or upgrade their wastewater treatment systems. Peru recently reduced their TSS standard to 250 mg/L, a trend reflected in other countries, along with new limits for sulphates (<100 mg/L at times), selenium, and TDS. While this drives market growth for more advanced treatment technologies, it also drives demand for digital monitoring solutions that can ensure operators are meeting these discharge limits.

In South Africa, the sector has been slow to adopt innovations even when already common practice overseas. Innovations do require contextualisation to the local situation but since this is a lower cost and lower risk option than inventing technologies from TRL 3 upwards, the following are recommended:

- An overhaul and active promotion and communication to the sector about the DSI's R&D tax incentives to decrease the financial risk of testing innovations, to educate the sector and to make the administrative burden of accessing the incentive worthwhile.
- A grace period for testing innovations that qualify for R&D tax incentives to de-risk the trial period in terms of compliance.

6.2.2 Practice

The MWCB in the Upper Olifants water management area and the coal research association, Coaltech, were named as impact partners whose collaborative activities lead to broader and faster access to innovations (both water-related and not). A roll-out of MWCBs nationally and replicating Coaltech's activities for other commodities could have an enormous positive impact on the actual market size and appetite for innovations.

6.2.2.1 Recommendations for mining companies

Our calls to actions to private and public sector mining companies and entities with tied mines are:

a) Allocate a realistic budget for more than minimal water management and treatment activity, and apportion part of the budget to trialling technologies at TRLs below 7 in operational environments.

b) Conduct calls for technologies and engaging actively with a diversified supply chain of technology developers and consulting engineers to inform the sector about available and emerging innovations.

c) Acknowledge that we can do things better. Conventional water management, treatment and monitoring methods and technologies are not always sufficient.

d) Place greater value on the post-mining landscape.

e) Adhere to regulations as a matter of principle, even if they are not vigorously enforced.

f) Internalise the real costs of water management into mine planning and costing at the planning stage.

g) Allow staff the liberty to become informed about emerging technologies and know-how through research events, journals, and free forums (e.g. WRC Reference Groups) without the requirement to provide an exact Rand value for each engagement.

h) Understand and accept the responsibility of informing research. Also understand that fundamental research is a years-long process, that most research does not product a disruptive technology, and that this is normal in conceptual R&D.

i) Understand and accept that research products can be EITHER tailored to specific needs OR they can be off-the-shelf. The two are mutually exclusive. If end-users want the former then they must be prepared to support the technology developers by providing information to guide its design, test beds to trial and develop innovations, and financial support.

6.2.2.2 Recommendations for professional bodies

The MWCB is becoming an effective catalyst for impact. It was established through the SWPN in 2016 but has since become an organisation in its own right, formed by Anglo American, the CSIR, Exxaro, World Vision South Africa and Zutari (an engineering consultancy) and housed within the Impact Catalyst. The MWCB uses public-private collaboration to drive large-scale, socioeconomic development, alleviate poverty and promote equality through job creation and improved healthcare in the Limpopo, Mpumalanga and Northern Cape provinces.

The recommended actions for associations are:

a) To investigate the creation of MWCB capabilities in mining areas outside of the Upper Olifants catchment, either through expanding the MWCB that exists or by establishment of other bodies in the other catchments where mining has an impact.

b) MINCOSA to investigate the merits of establishing research collaborations like Coaltech for the other commodities, and to bring the junior miners into the MINCOSA community.

6.2.3 Future research

A repeated observation from the mining companies was that academic research was not focused on the correct problems faced by the industry, and that it proceeded too slowly. An observation from researchers was that the intended users of their research products wanted them to develop something tailored specifically to their very narrow needs (sometimes the needs of a single site) but without investing time or funding into the innovation.

The most effective academic researchers in the mine water space are those with previous careers in industry. There are good examples at the University of the Western Cape, University of the Witwatersrand, and University of Cape Town where mining sector professionals have become academics and undertake highly impactful practical research.
We therefore recommend that:

a) Academic researchers should capitalise on the networks offered by collaborative organisations like the WRC, SAIMM, Coaltech, AMIRA, ICMM and WISA MWD much more actively to build relationships with individuals and organisations who are the intended users of their research products. A consistent effort is required to draw users in as active participants in R&D from TRL 3 onwards.

b) Innovation developers need to accept the responsibility undertaking informed research.

c) Technology developers need to understand and act on the fact that their innovations are not market ready unless the market says they are. Innovators should either provide the type of business and commercial information the users are asking for, or a clearly articulated genuine reason why the information does not yet exist.

d) Innovators should learn about and be open to the variety of benefit-sharing agreements through which investors can be attracted to new technologies.

6.2.4 Funding and Financing

Currently, mining companies are required to set sufficient funds aside for site rehabilitation, remediation and maintenance after closure. The regulations do not require a portion of funding to be allocated for the development of innovations that limit the rehabilitation, remediation and maintenance activities. However, the regulations also do not preclude doing so, and it has potential as a means of attracting companies spend on enterprise and social development that could be used to develop innovation.

Government and the private sector are both linked to the funding of rehabilitation of closed mines and prevention of legacy issues in the future from currently open mines. South Africa needs a stable funding mechanism in place that can implement novel and conventional know-how and technologies to address ownerless and derelict mines over the next 10-25 years, and in parallel prevent open mines from becoming ownerless and derelict. There are four options which should be explored:

a) Direct government funding from general revenues;
b) Government funding through tapping existing revenue streams generated by mining (e.g. mining tax / royalties);
c) Government funding through the imposition of a levy on current and future mined product generation; and
d) Government-industry partnership.

Direct funding from general revenues is based on the premise that the issue of ownerless and derelict mines can be addressed through the appropriation of funds from general revenues via government planning and budgetary processes. This is the mechanism through which previous work on ownerless and derelict mines has been carried out. The main negative feature of this option is that it is not stable, due to changing government priorities, planning changes by the bureaucracy, or the appointment of new Ministers or staff with different agendas.

Government funding through tapping into existing mining revenue streams requires diverting either front-end royalties or mining royalties (back end taxes on profits) into a dedicated fund. This option has the merit of producing funds from mining-derived revenues. It requires a jurisdiction to collect sufficient royalties to create a meaningful and stable fund; this is unfortunately subject to the booms and busts of the mining cycle. Legislation would need to be put in place to make this option stable.

Option c) is based on the principle that a large enough and stable enough fund could be created by establishing a legislated levy on current mining production. This principle has been in discussion for over a decade and was recommended as a course of action in 2010 (Expert Team of the Inter-ministerial Committee, 2010). This option guarantees a revenue stream (although it is also subject to the mining commodities cycle). It has been used successfully in the USA, where a levy on coal production has produced a large source of funds for the rehabilitation of coal mines (Dean, 2021a). The levy idea can only be used where the financial burden can be passed on directly to the consumer (e.g. coal and construction aggregates). For price-taking commodities like metals, the burden cannot be passed on and this option would impact the producers. Legislation would be required.

The last option, that of creating partnerships with mining companies to fund mine water management and treatment, is premised on the idea that both groups are willing and able to make arrangements to accomplish the common goal. Partnerships succeed when the mining companies want something from government – usually indemnity against future liabilities, or sharing of costs in exchange for access to resources or waste reprocessing rights (Tremblay and Hogan, 2006). This option can result in a win / win situation so both the government and the mining companies should be open-minded and willing to design partnerships whereby both benefit. Having said that, partnership approaches tend to be limited to single sites and have never been implemented (to our knowledge) as national or provincial, stable, long-term funding options.

The project team searched for case studies in which pooled financial resources have been held by a joint venture or special purpose vehicle and have been successful. Recent cases were not found but one report from 2003 (Castrilli, 2003) outlined and recommended a variety of funding approaches for consideration in the cleanup or management of liabilities related to ownerless and derelict mines in Canada. Castrilli recommended a combination of a number of approaches that were developed based on Canadian law. One recommendation was for a toolkit of funding options which was developed out and illustrated with case studies (Cowan and Mackasey, 2006).

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APPENDIX A: READINESS LEVELS

A.1 TECHNOLOGY READINESS LEVEL (TRL)

Technology readiness level		Description
1.	Basic principles observed and reported.	Scientific research begins translation to applied R & D. Desk studies of published peer reviewed papers.
2.	Technology concept and / or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.
3.	Analytical and experimental critical function and / or characteristic proof of concept.	Active R&D initiated (physical validation in laboratory).
4.	Technology component validation in laboratory environment.	Basic technological components are integrated to establish they will work together.
5.	Components and technology validation in relevant environment.	Technology tested in a large bench scale laboratory environment using real world fluids, data or set points (more realistic simulation).
6.	Prototype demonstration in a relevant environment.	Prototype evaluation in a simulated laboratory operational environment.
7.	Prototype demonstration in an operational environment.	Whole system prototype evaluation in actual operational environment (on a water, wastewater, or network site).
8.	Actual technology completed and qualified through test and demonstration.	Final phase of technology development; validation of technical performance and compliance with design specifications (Initial commercial trials).
9.	Actual technology proven through successful operations.	Actual commercial application of the technology in its final form and under real world conditions (commercial trials).

A.2 COMBINED MARKET READINESS LEVEL (MRL)

Level	Demand Readiness	Market Readiness
1.	Occurrence of feeling "something is missing".	An acceptance that viable improvements can be made.
2.	Identification of specific need.	Ability to highlight where the improvement can be made.
3.	Identification of the expected functionalities for a new product / service.	Being able to identify what the system should do.
4.	Quantification of expected functionalities.	Putting numbers on what is expected in terms of a solution, financially and technically.
5.	Identification of system capabilities.	Ability to define how the system should operate and integrate.
6.	Translation of the expected functionalities into needed capabilities to build the response.	Identify on a component level what the system should be comprised of.
7.	Definition of the necessary and sufficient competencies and resources.	An understanding of who should be planning, designing, and implementing the solution.
8.	Identification of the experts possessing the competencies.	Having contact with the people, internally or externally, who will design and create the solution.
9.	Building the adapted answer to the expressed need in the market.	Solution is being created to solve a defined problem.

APPENDIX B: INNOVATION PROCESS FLOW AND SITUATIONAL ANALYSIS METHODOLOGY

In order to address the aims of the project efficiently and effectively, a phased approach was developed as outlined in Table 11.

Table 11: Outline methodology

Phase	Phase Name	Outline Description
1	**Innovation Process flow & Situational Analysis**	Addressing a variety of stakeholders (mining companies, mining associations, Regulatory / Research) define how innovations flow from concept to installation. Understand the processes, barriers and opportunities, market size, etc. The impacts of regulatory changes and other economic impacts within related sectors such as construction will also be documented.
2	**Market Insight**	Mapping innovation trends against innovation needs as articulated by technology users and mining sector regulators. Insights were used to validate future investment into further business developments.
3	**Critical Analysis**	Using the findings from Phases 1 and 2, the critical analysis will develop recommendations for future research, policy developments and the transition of best practice to business as usual.

Elements of phases 2 and 3 were addressed during the steps in Phase 1 in order to ensure efficiency of contact and to limit the time we take up of those taking part in the discussions / interviews.

Figure 33 depicts the steps involved in each phase of the project.

Figure 33: Flow diagram summarising the project methodology

B.1 PHASE 1: INNOVATION PROCESS FLOW & SITUATIONAL ANALYSIS

The project involves a range of stakeholders who all play an important role in the mining sector, either as a mining industry consumer of innovative solutions; a trade association body that raises awareness, educates and lobbies around pertinent issues; or as a Regulator helping to shape and deliver regulations that can impact the industry's focus on innovative solutions (and others).

B.1.1 Mining companies

The first phase of the project aims to generate a detailed understanding of the processes undertaken by mining companies (as consumers of water innovations) to facilitate their learning and subsequent uptake of mining water innovations. We will do this by identifying the high level innovation processes adopted by each organization, using a structured questionnaire to help guide the individual (confidential) conversations. The output of this step will in turn be used to identify where interventions would be beneficial to the flow of innovations from concept to adoption.

A total of 47 mining companies were asked for participation. They included all sizes of company (small to large multinational) and all commodities. Two of the interviewees were from outside South Africa and used as an international reference while 45 were either in the South African business of a multinational or were solely South African companies. The response rate was 42% and the participation rate was 31%. Many of the interviewees asked to remain anonymous.

The questions for the mining companies have been designed to enable a high level view of the processes, strategies, metrics, success rates, perceived barriers, and thoughts around what changes / interventions might be required in order to accelerate / enhance innovative solution uptake. Table 12 provides details of the questions covered:

Table 12: Mining company discussion structure

<table>
<tr><td>Interviewee</td><td></td><td>Interviewer</td><td></td></tr>
<tr><td>Position</td><td></td><td></td><td></td></tr>
<tr><td>Company name</td><td></td><td></td><td></td></tr>
<tr><td>Date of interview</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Company policy and systems for identifying and assessing emerging technology</td><td colspan="2">proactive / reactive / responsibilities for initiating trial / responsibilities for adopting technology / budget / staffing / reliance on own assessment vs 3rd party technology approval / collaborative trials with other mining companies / innovation champions</td></tr>
<tr><td colspan="2">Does your organisation have an innovation strategy?</td><td colspan="2">In place / in development / do you see a role for an innovation strategy / is there an associated budget?</td></tr>
<tr><td colspan="2">How does your organisation make the supply chain aware of the challenges you are seeking innovative solutions too?</td><td colspan="2">Releasing challenge statements / running competitions / developed challenge / needs roadmaps / speaking at conferences / blogs / website / word of mouth</td></tr>
</table>

Do you have a hold on the size of the challenge? E.g. Quantity of impacted mining water released, catchment areas affected, ground water bodies, geographical areas	
What is your organisations appetite to capture and treat mining-impacted waters?	Split the focus down to prevention, minimisation, management, and treatment
What are the drivers for the uptake up mine water treatment solutions?	
Perceived barriers within the mining company to uptake of emerging technology	regulatory risk / financial risk / service risk / lack of incentive / vested interests / technology issues / SME size / SME financial standing /
Which mine water treatment engineering companies do you work with?	
Success / failure criteria for trials	technical competence / cost savings / risk reduction / business case
Emerging technologies trialled in the last 5 years	name / brief description of technology / trial duration / trial cost / outcome / what was the driving factor to undertake a trial?
Emerging technologies adopted in the last 5 years without trial	name / brief description of technology / outcome / what was the driving factor for solution adoption?
Are there domestic market leaders for the provision of trusted mine water innovations?	
Are there suitable test facilities to trial a solution in a ‘safe’, controlled environment?	This leads on to running live trials – are there suitable locations for these too?
How might the flow of innovations into your organisation be better supported?	External programmes / Regulation changes / Upskilling employees / improving the culture for innovation /
How can solution providers with an emerging technology to offer increase their chances of success with the mining company?	presentation skills / business awareness / company structure / company finances / knowing the client and their business / technical knowledge / price / business case
What must the solution provider do / not do to avoid a speedy dismissal?	
How do you currently monitor your pump out schedules and what is your role throughout this process?	
If you could change one thing to increase the uptake of emerging technologies in your company, what would it be?	
Are you aware of business / incentive models used elsewhere that in the country / world that you feel would help to drive take up mining water treatment & management innovations?	
Other items	Use this space for anything else that is relevant and not already recorded above

The findings from this step were visually presented in a diagram based on the innovation cycle image below in order to quickly see which stages the majority of the activity takes place in, and therefore to identify gaps (Figure 34).

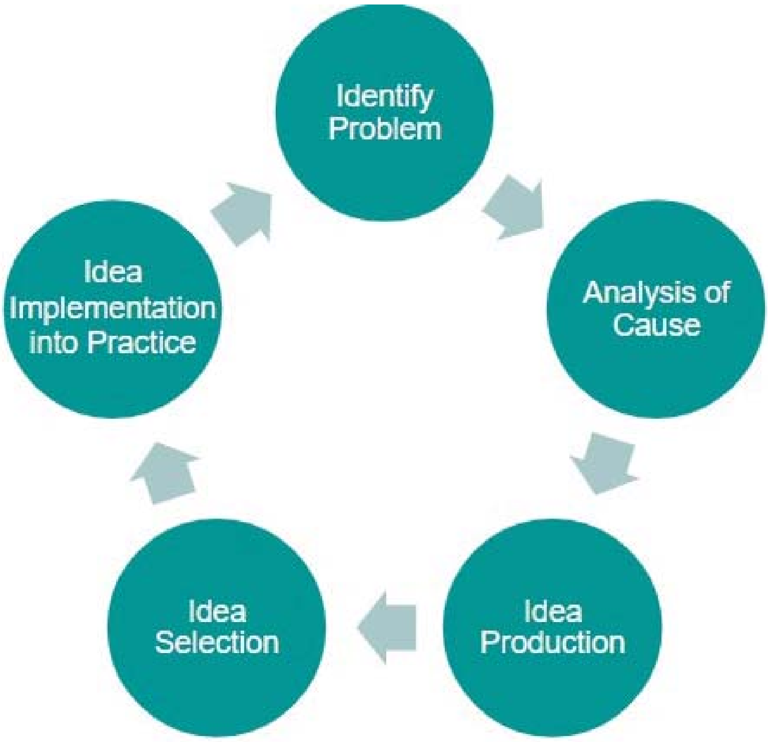

Figure 34: The innovation cycle

B.1.2 Mining Associations

Mining associations are important stakeholders to engage in the market demand analysis process, as they are dedicated to helping promote mining and mineral products and to create an enabling environment in which the industry can prosper (MIASA, 2020), they are also a key source of information regarding:

- Core issues relating to the mining industry (economic, energy, environment, and infrastructure)
- Facts, statistics, and data
- Regulation
- Best Practice
- Events

The mining associations will have excellent insight to the industry level activities, plans and capabilities. For this reason, the questions used to guide discussions with the organisations listed below, will follow the format outlined in Table 13.

- The International Council on Mining and Metals (ICMM)
- Coaltech 2020 Research Association
- International Mine Water Association (IMWA)
- Mine Water Division of the Water Institute of Southern Africa (MWD)
- International Network for Acid Prevention (INAP)
- Global Alliance
- Mining Precinct
- AMIRA International Ltd.
- National Coal Authority of England and Wales

The associations listed above have been selected to provide a detailed understanding of the South African sector, as well as an international situation against which the domestic situation may then be compared. The multinational associations (e.g. IMWA, INAP, ICMM) may themselves provide opinions on the global landscape.

Table 13: Mining association discussion structure

Interviewee		**Interviewer**	
Position			
Company name			
Date of interview			
Sector level policy and systems for identifying and assessing emerging technology			
Is there a sector level innovation strategy?		In place / in development / do you see a role for an innovation strategy / is there an associated budget?	
How does your organisation make the supply chain aware of the challenges the sector is seeking innovative solutions too?		Releasing challenge statements / running competitions / developed challenge / needs roadmaps / speaking at conferences / blogs / website / word of mouth	
Do you promote solutions that have been trialled successfully by the sector so that learning can be shared?		Where, how, in partnership?	
Perceived barriers within the mining company to uptake of emerging technology		regulatory risk / financial risk / service risk / lack of incentive / vested interests / technology issues / SME size / SME financial standing /	
How might the flow of innovations into the mining sector be better supported?		External programmes / Regulation changes / Upskilling employees / improving the culture for innovation /	
How can solution providers with an emerging technology to offer increase their chances of success with the mining company?		presentation skills / business awareness / company structure / company finances / knowing the client and their business / technical knowledge / price / business case	
Do you feel you are in a position to influence future regulations that will affect the mining sector from a water perspective?			
How do you see your role in terms of defining and driving key focus / priority areas and maximizing economic, social, and environmental impact?			
If you could change one thing to increase the uptake of emerging technologies in your company, what would it be?			
Other items		Use this space for anything else that is relevant and not already recorded above	

B.1.3 Regulatory and research bodies

A desk top study was conducted to investigate and document relevant legislation, regulation and guidelines relating to mining water treatment and management. The study will document information specifically from:

- Directorate: Mine Water – Water Quality Management within the Department of Water and Sanitation
- Department of Minerals and Energy
- Department of Environment, Forestry and Fisheries.

Mintek and the Water Research Commission were engaged in order to ensure that the broader perspective is also captured. Insight from these two organisations was captured through semi-structured discussions focusing on:

- Their interpretation of the impact of current legislation, regulation, and guidelines
- Where they believe future amendments to these regulatory rules may occur
- Where they believe changes are required if the uptake of innovative mining water treatment and management solutions are to be more widely adopted by the mining community

When other relevant sources were highlighted through the interviews / discussions undertaken with the mining companies and associations, they were included in the desktop study scope.

The high-level impact of the regulatory provisions identified was assessed in order to determine if they have individual or combined impacts on (or the potential to):

- Driving innovation
- Hindering Innovation
- Creating new market opportunities

Findings were documented in a report formation with all information sources recorded.

Research organisations across South Africa were assessed for their mining water related expertise, sector standing, sector influence and as contributors to the flow of innovative solutions into the mining community.

A desktop study was used to provide details of the key research organisations involved in mine water treatment and management. Contact with each relevant organisation was then established, using existing contacts as much as possible. Semi-structured discussions were undertaken, addressing the areas listed in Table 14.

The findings of the semi-structured discussions were used to determine how well the research and business activities align with the regulatory requirements.

Perceived market opportunities as a result of current or emerging legislation / regulation / guidance activities were drawn out and documented.

These combined findings enabled us to conclude how well aligned the sectors current activities are.

Table 14: Research organisation insight & understanding

Interviewee		**Interviewer**	
Position			
Company name			
Date of interview			
To enable the emergence of innovative solutions, how do you maintain an in depth understanding of industry, policy, Government and Regulatory needs?			
How do you currently engage with the Regulators and Policy Makers?			
How do you engage with industry and technology developers?			
What partnerships need to be enhanced or developed to ensure your market insight is maintained?			
What are the organisations key areas of research relating to mine water?			
Which departments are involved in mine water related research?			
Does your organisation hold any IP relating to mine water?			
Does your organisation have established mechanisms for technology commercialisation and exploitation as a result of successful research programmes?			
What / who are the key sources of funding for mine water related research?			
Are there any market / regulatory / environmental or social trends that you foresee impacting the level of mine water related research in the future?			
Are there any emerging topics of interest from a mine water perspective?			

B.2 MARKET ASSESSMENT

B.2.1 Current market

In order to analyse the South African market for mining-impacted water treatment and management innovations and to forecast the future market size and shape by considering mining sector economics, likely regulatory changes, and economics of related sectors (for example construction, which drives demand for iron and steel), a situational analysis was conducted using interview based findings (interviewing mining companies and engineering companies) following the format in Table 15. These findings were combined with a desk top study and existing market knowledge to generate the market forecast (see Appendix C). The outputs were documented in a detailed report following the market segmentation analysis.

Table 15: Mining related water treatment and management innovations, market assessment

Interviewee		**Interviewer**	
Position			
Company name			
Date of interview			
Customers: What market segments do you supply? What markets do your materials end up in (if known)?			
Customers: What percentage of your turnover is proportioned to each market segment?			
Customers: Do you sell direct to wholesalers / distributors? Provide details.			
Customers: Are there any notable trends in your customers buying habits?			
Customers: Who are your current and potential customers?			
Competitors: Who are your key competitors?			
Competitors: What political factors currently, or might, impact your potential to compete in the mining markets?			
What economic factors currently, or might, impact your ability to supply your clients?			
What social factors (skills, contractual, workforce availability, etc.) currently, or could impact your ability to supply your clients?			
Are there any technological factors that currently impact, or could impact, your ability to supply your clients?			
Are there any current or foreseen legal (regulation or legislation) factors that could or do impact your ability to supply your clients? Might these legal changes affect the market segments your currently supply?			
Are there any environmental considerations that impact, or could impact, your ability to supply your clients?			
Do you foresee the threat of any new entrants into the market?			

B.2.2 Analysis of the market segmentation

The market share held by the domestic providers of the leading mine water innovations was estimated using the combined results from the previous interview findings, together with undertaking follow up discussions and desktop studies to further understand:

- Customer / Client divisions
- The factors driving market uptake (regulatory, customer value / benefit, environmental benefit, social corporate responsibility, etc.)
- Behavioural – to understand how relationships and trust are impacting market share and segmentation.

The outputs from this section of the project deliver insight and understanding of the opportunities and impacts for and of the potential uptake of innovative mining water treatment and management solutions.

B.3 PHASE 2: MARKETS INSIGHT STUDY

A global best practice desktop study was undertaken for comparison with the South African situation, primarily focusing on the UK, USA, and Australia.

The UK was of particular interest as they are experienced at dealing with the legacy problems remaining after the vast majority of mines in the country have been closed. Australia and the USA were studied in order to ensure the range of resources mined, and therefore the different market drivers, expectations, demands, and impacts were captured. The best practice study will capture examples of good practice in innovation management, trial, and deployment, together with the governance and support structures and systems supporting the innovation activities.

A review of best practice examples from the British Water Sector will also be included. The water sector is relatively experienced at assessing and understanding the factors impacting the innovation cycle and the development and adoption of innovation solutions. They are also highly regulated and so face numerous economic, social, and environmental challenges and risks.

Using the findings from Phases 1 and 2 together with published information (which was captured and referenced appropriately), we mapped (in Figure 13and Figure 14) the structure of the South African mining water treatment water, specifically identifying activities in and involving:

- Mining-impacted water prevention
- Mining-impacted water minimization
- Mining-impacted water management
- Mining-impacted water treatment

The diagrams detail the relationships between the innovation drivers, adopters, supporters, and developers. This will include details identified from Phases 1 and 2 relating to regulation and jurisdiction.

It should be noted that several of the investigatory questioning required in Phase 2 were addressed during the interviews undertaken in Phase 1. The process has purposefully been designed in this manner to ensure we limit the number of contacts and duration of time demand on individuals within the relevant stakeholder groups. We aimed to capture as much information through one conversation as possible.

In order to identify the approaches taken by engineering companies, we undertook interviews with mine water treatment engineering companies who are currently undertaking mine water projects. We specifically drew out their approaches to their clients (to identify opportunities) and the trial, management, and implementation of mine water solutions. The mine water treatment engineers engaged by the mining companies were identified through the confidential discussions undertaken as part of Phase 1: Innovation Process Flow & Situational Analysis. The interviews were structured using the questions listed in Table 16.

Table 16: Mining engineering company interview template

<table>
<tr><td>Interviewee</td><td colspan="2"></td><td>Interviewer</td><td colspan="2"></td></tr>
<tr><td>Position</td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>Company name</td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>Date of interview</td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>Description of Company</td><td colspan="5">Age of company / number of employees / number of offices / locations</td></tr>
<tr><td>Turnover in last full FY</td><td><R2 million</td><td>R2-R10 million</td><td>R10-R20 million</td><td>R20-R100 million</td><td>>R100 million</td></tr>
<tr><td colspan="2">Description of business</td><td colspan="4">Products / services / market sector / Core IP</td></tr>
<tr><td colspan="2">Understanding of the (water) challenges faced by the mining companies</td><td colspan="4">Ways of identifying & understanding the challenges / ways of engaging with the mining companies /</td></tr>
<tr><td colspan="2">Innovative concepts developed / being developed</td><td colspan="4">When / what / funding sought (amount and from) / funding obtained (amount and from) / concepts that failed to get traction, reasons. Including Business Models.</td></tr>
<tr><td colspan="2">Research – insight</td><td colspan="4">Understanding of direction of travel as indicated by research</td></tr>
<tr><td colspan="2">Experiences of obtaining funding</td><td colspan="4">Regional initiatives / schemes applied for / schemes awarded / investors / encountered / the application process / making up the difference between project cost and funding obtained</td></tr>
<tr><td colspan="2">Experiences of IP protection</td><td colspan="4">availability of advice / patent, trademark, registered design / cost of protection</td></tr>
<tr><td colspan="2">Experiences of innovation in the mining companies</td><td colspan="4">Target market / market uptake / successes achieved / difficulties encountered / resistance to change / attitude to risk / concept to revenue (C2R) cycle time /</td></tr>
<tr><td colspan="2">Is the current innovation environment satisfactory?</td><td colspan="4">What is helpful? / What is obstructive? / What is missing? / Is information readily available? / Are clients receptive to new ideas?</td></tr>
<tr><td colspan="2">How could the environment be improved to accelerate the uptake of innovation?</td><td colspan="4">More advice? / better advice? / shorter C2R cycle? / client attitudes? / access to funds? / financial regulation? / tax incentives? / competition?</td></tr>
<tr><td colspan="2">If you could change one thing to increase the uptake of emerging technologies, what would it be?</td><td colspan="4">Be ambitious!</td></tr>
<tr><td colspan="2">Other items</td><td colspan="4">Use this space for anything else that is relevant and not already recorded above.</td></tr>
</table>

Using the findings from Phase 1, the output of the interviews with the relevant engineering companies from Phase 2, a range of domestic mine water innovation developers (technology developers) were interviewed using the interview template provided in Table 17.

The findings from Phase 2 were used to outline the developments required to improve the market structure from a supplier, buyer, manufacturing, penetration, affordability, regulatory and environmental perspective.

Table 17: Technology developer interview template

<table>
<tr><td>Interviewee</td><td colspan="2"></td><td>Interviewer</td><td colspan="2"></td></tr>
<tr><td>Position</td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>Company name</td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>Date of interview</td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>Description of Company</td><td colspan="5">Age of company / number of employees / number of offices / locations</td></tr>
<tr><td>Turnover in last full FY</td><td><R2 million</td><td>R2-R10 million</td><td>R10-R20 million</td><td>R20-R100 million</td><td>>R100 million</td></tr>
<tr><td colspan="2">Description of business</td><td colspan="4">Products / services / market sector / Core IP</td></tr>
<tr><td colspan="2">Exposure to business accelerator programmes</td><td colspan="4">Name of programme / date / cost / equity required / services received / What did it help you to achieve? / How could it have been improved?</td></tr>
<tr><td colspan="2">Innovative concepts developed / being developed</td><td colspan="4">When / what / funding sought (amount and from) / funding obtained (amount and from) / concepts that failed to get traction, reasons</td></tr>
<tr><td colspan="2">Experiences of academia</td><td colspan="4">Researchers / administrators / commercialisation / costs / time-scales</td></tr>
<tr><td colspan="2">Experiences of obtaining funding</td><td colspan="4">Regional initiatives / schemes applied for / schemes awarded / investors / encountered / the application process / making up the difference between project cost and funding obtained</td></tr>
<tr><td colspan="2">Experiences of IP protection</td><td colspan="4">availability of advice / patent, trademark, registered design / cost of protection</td></tr>
<tr><td colspan="2">Experiences of innovation in the mining companies</td><td colspan="4">Target market / market uptake / successes achieved / difficulties encountered / resistance to change / attitude to risk / concept to revenue (C2R) cycle time /</td></tr>
<tr><td colspan="2">Is the current innovation environment satisfactory?</td><td colspan="4">What is helpful? / What is obstructive? / What is missing? / Is information readily available? / Are clients receptive to new ideas?</td></tr>
<tr><td colspan="2">How could the environment be improved to accelerate the uptake of innovation?</td><td colspan="4">More advice? / better advice? / shorter C2R cycle? / client attitudes? / access to funds? / financial regulation? / tax incentives? / competition?</td></tr>
<tr><td colspan="2">If you could change one thing to increase the uptake of emerging technologies, what would it be?</td><td colspan="4">Be ambitious!</td></tr>
<tr><td colspan="2">Other items</td><td colspan="4">Use this space for anything else that is relevant and not already recorded above.</td></tr>
</table>

B.4 PHASE 3: SYNTHESIS AND CRITIQUE

The final phase of the project drew all the findings of the different project phases together. A critical analysis of the findings was undertaken so that recommendations could be made regarding: Future research, Policy, and Innovation in practice.

The recommendations draw upon the experiences noted from the best practice examples in both mining and water sectors around the world, and consider the perspective of techno-economics, practicality, and permissibility under the current policy and regulatory positions together with the potential changes to these drivers.

APPENDIX C: FORECAST METHODOLOGY

The forecast was informed by data sourced from SNL Financials' Mining and Metals data service, which includes information about mining production and future projects, as well as a breakdown of capital costs. Data on industrial output, water use statistics, assumptions about typical treatment trains and the cost of treatment technologies were combined to produce an estimate of the value of water-related spending in the sector. The CapEx forecast does not include the costs of civil engineering, construction, and electricity as it is impossible to distinguish water-related expenditure from the rest of the construction at a site. Spending was subdivided into the following applications:

Process / drinking water treatment:	Includes spending associated with the treatment of water use in processes that do not require a high level of treatment.
Wastewater treatment:	Includes spending associated with the treatment of wastewater streams except AMD and ARD, and the sludge produced during wastewater treatment.
Desalination:	Includes spending associated with the treatment of brackish water to reduce the concentration of solids in saline water to a concentration acceptable for use.
Ultrapure water treatment:	Includes spending associated with the treatment of water to an acceptable purity for use in boiler and steam systems.

C.1 PRODUCTS

Capital and operating expenditure were divided into the following seven broad categories:

Labour (OpEx)	Includes salaries and other benefits paid to people directly employed for the operation of water and wastewater systems. Based on informed assumptions about the percentage of total operating costs that go towards labour, as well as the likelihood that this would be in-house or outsourced.
Energy (OpEx)	Includes the electricity and fuel costs required for treatment operations and for moving water around industrial facilities. Based on informed assumptions about the energy required per unit volume of water and the typical cost of energy (as at June 2021).
Equipment (CapEx and OpEx)	In CapEx, this includes equipment in new build, expansion, rehabilitation, and upgrade projects. In OpEx, this includes replacement parts and aftermarket services. Each sector and equipment category is based on the typical proportion of sales that come from replacement parts.
Chemicals (OpEx)	Includes the cost of chemicals required for process water treatment, wastewater treatment, sludge conditioning, internal boiler and cooling system conditioning, and other uses such as dust suppression.

Services (OpEx)	Includes spending on outsourced operations contracts, payments under BOT contracts, payments to service providers, equipment maintenance contracts, services related to the maintenance of filtration media and other consumables, services related to the supply of chemicals and consumables, mobile water solutions and other specialist services. Estimates of the size of the outsourced operations and mobile water solutions markets, are based on assumptions about the percentage of the total operations market that is penetrated by these services and how this percentage would increase in the future given the current state of the market. Estimates of spending under BOT contracts are based on assumptions made about the percentage of total capital spending that occurs under such contracts, and how increases in this percentage will drive corresponding increases in OpEx and customer payments under these contracts. Estimates of spending on services related to chemicals, parts and consumables are based on assumptions about the typical percentage of sales contracts that have a service element. Estimates for spending on equipment maintenance contracts, media and consumables services, and specialist services are based on the opinion of experts with experience of these markets, and the relative size of equipment and chemicals spending in different sectors.
Other project costs (CapEx)	This includes CapEx on non-equipment products and services in a construction project, such as sitework, civil engineering, design costs, legal and professional costs, etc.
Utility services (OpEx)	This includes payments to municipal utilities for water supply and wastewater discharge. To estimate this, we have made assumptions about the percentage of utility revenue from industrial customers in mining areas.

C.2 TECHNOLOGY AREAS

The Technology Area categories in the forecast are:

Biological treatment	Technologies that use biological methods to reduce organic carbon or nutrient levels. Aerobic, anoxic, and anaerobic methods, and both free-film and fixed film technologies have been included.
Disinfection	Systems using chlorination, ultraviolet light, ozonation, and advanced oxidation to inhibit the growth of microorganisms and oxidise organic compounds.
Dissolved solids removal	Technologies that remove dissolved solids. This includes membrane processes, thermal desalination equipment, ion exchange, electrodialysis / deionisation, brine concentration, etc.
Fluid handling equipment	Pipes, pumps, and valves that are used to transport water and wastewater through networks and treatment plants. Does not include channels, pumps that are part of chemical feed systems or valves for controlling the flow of other substances.

Physical / chemical treatment	The combination of suspended solids removal and oil-water separation. Technologies that remove suspended solids by settling, filtration, and flotation, such as clarifiers, induced / dissolved air flotation, media filtration, MF / UF, etc. and technologies such as gravity separators, hydrocyclones, etc. and activated carbon.
Sludge management	Technologies for managing and reducing the volume of sludge that is produced by other treatment processes, such as gravity thickeners, belt thickeners, filter presses, anaerobic digestion, chemical stabilisation, composting, etc.

C.3 OTHER PROJECT COSTS

Other project costs include any non-equipment costs in CapEx. The categories are:

Design and engineering	Includes any costs related to project design and engineering for treatment plant, network, and industrial projects. Does not include engineering costs related to sitework or construction.
Civil engineering / fabrication	Includes labour, installation costs and generic materials (e.g. concrete, steel, etc.) associated with water and wastewater treatment systems, as wells as custom metal fabricated industrial process equipment. Does not include general civil engineering and construction costs at project sites.
Regulatory and professional costs	Includes the cost of any legal and financial services, as well as services related to environmental permits for water withdrawals and discharges.
General construction / other	General water-related spending at project sites.

C.4 TECHNOLOGIES

The technology forecast integrates the separate treatment technologies (oil-water separation, suspended solids removal, dissolved solids removal, biological treatment, disinfection, sludge management) and equipment forecasts into a single dataset within which the market is divided into six broad technology areas:

- Biological treatment
- Disinfection
- Dissolved solids removal
- Fluid handling
- Physical / chemical treatment
- Sludge management

Interviews with market stakeholders and experts were conducted to gather specific estimates relating to the market size and dynamics for individual technologies, systems, and components. These were then combined to create estimates for the broader technology areas, with these estimates, in turn, combined to give a total estimate of the overarching technologies market.

On top of the six treatment technology categories (above), the market has also been divided between spending on control and monitoring systems and construction costs.

- Spending on control & monitoring systems falls under the separate ‘Digital’ forecast.

- Construction costs includes civil engineering, fabrication, design engineering, regulatory and professional costs. These costs were estimated using the percentage of a typical project budget in the mining sector.

It should be noted that the technology forecasts are subject to substantial variations in local pricing, technology choice and plant configuration from project to project. The forecast attempts to represent the national market accurately. However, this variation means that there may be some discrepancy between our estimates and the actual situation.

C.5 DIGITAL

The forecast is built on a model that divides spending on data collection, control & monitoring, and data management & analytics solutions between different categories, including product types, applications, and parameters. The model estimates the percentage of total spending that is directed towards these solutions, and then how this spending is split between these categories.

The starting point for the model is estimated total water-related spending, which is derived from The Global Water Market forecast. The percentage of total spending that will be directed to digital solutions was informed by interviews, information from individual projects, and estimates of the unit cost of different components. The forecast is broken down into three market sectors: product type, application, and parameter.

Spending on each product category was divided by their application. The divisions were made by analysing which parameters were measured within each process, and the typical unit cost associated with each one. The breakdowns were then cross-checked with information collected from interviews. Applications include intake / process water treatment, wastewater treatment, and networks. Information about which parameters were measured in each application, and the typical cost of the equipment to measure each parameter were used to estimate the division of spending for each parameter in each application category. Experts were consulted with when available to check the validity of these divisions.