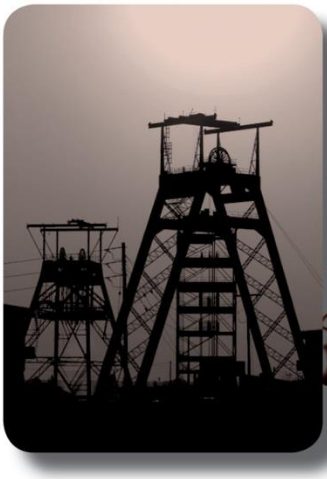
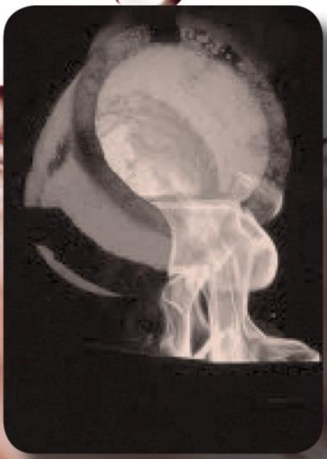


Water Resource Planning Systems Series

Water Quality Planning

Feasibility Study for a Long-Term Solution to address the Acid Mine Drainage associated with the East, Central and West Rand underground mining basins

Options for Use or Discharge of Water

Study Report No. 5.3

P RSA 000/00/16512/3

May 2013

EDITION 1



water affairs

Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF WATER AFFAIRS

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Disclaimer:

The study was very dynamic in nature and the available information is continuously being updated and expanded. It is confirmed that each report has been prepared for the purpose of the study using the information relevant and available at the time of compilation of the report. All necessary skill, care and diligence were exercised by the authors, contributors and reviewers during the compilation and approval of the reports. The reader needs to determine the relevance, reliability or usefulness of the information and data reported in this study, if it is used in whole or in part, for their own purpose. Reports should not be interpreted in isolation, but in the context of the study and all its deliverables as a whole.

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SC: Study Component Conf: Indication of Confidentiality

 # - These reports will not be made available until the appropriate implementation process stages have been reached as they may potentially compromise future procurement and legal processes.

PREFACE

1. Background to the Study

Gold mining in the East, Central and West Rand underground mining basins of the Witwatersrand goldfields (hereafter referred to as the Eastern, Central and Western Basins) started in the late 1880s. It is estimated that in the 1920s approximately 50% of the world's gold production came from the Witwatersrand mining belt, while in the 1980s South Africa was still the largest gold producer in the world. The large-scale mining in South Africa, in particular on the Witwatersrand, has decreased since the 1990s, and underground mining on the Witwatersrand essentially ceased in 2010. The mines of the Western, Central and Eastern Basins have produced a total of approximately 15 600 tons of refined gold since mining commenced. While the mines were operating, they pumped water to the surface to dewater their mine workings, but since mining stopped, the underground voids that were left after the mining have been steadily filling with water. The water in the mine voids interacts with the exposed sulphide bearing minerals in the rock formations to form Acid Mine Drainage (AMD), also known internationally as Acid Rock Drainage (ARD). AMD is characterised by a low pH and an excessive concentration of dissolved metals and sulphate salts.

In the case of the Western Basin, the AMD gradually reached the surface and started to drain out (decant) into surface streams in 2002. The water in the mine voids of the Central and Eastern Basins is rising steadily and will continue to do so until the water is pumped from the voids. It is predicted that the critical water levels will be reached in the Central Basin in late 2013 and in the Eastern Basin in mid-2014. If nothing is done, the water is predicted to reach the surface and decant at the lowest points in the Central Basin in the second half of 2015 and to reach the surface and decant in the Eastern Basin in late 2016. Decant would be uncontrolled and is likely to occur at several identified points, as well as at unexpected locations across each basin, due to varying water levels and connectivity between the near-surface aquifers and the voids.

If AMD, which has not been desalinated, is discharged into the Vaal River System, the high salt load will require large dilution releases to be made from the Vaal Dam to achieve the fitness-for-use objectives set for the Vaal Barrage and further downstream. This would result in unusable surpluses developing in the Lower Vaal River. Moreover, if dilution releases are still required after 2015, the acceptable levels of assurance of water supply from the Vaal Dam would be threatened. This will mean that there would be an increasing risk of water restrictions in the Vaal River water supply area, which will have negative economic and social implications. These negative impacts will be much greater if the catchment of the Vaal River System enters a period of lower-than-average rainfall with drought conditions. Since decant started in the Western Basin in 2002 the continuous flow of untreated AMD, and now the salt load from the continuous flow of the neutralised AMD from the Western Basin, impact on the Crocodile (West) River System.

The importance of finding a solution to the rising AMD and the need for inter-departmental cooperation led to the establishment of an Inter-Ministerial Committee (IMC) on AMD, comprising the Ministers of Mineral Resources, Water and Environmental Affairs, and Science and Technology, and the Minister in the Presidency: National Planning Commission. The first meeting of the IMC took place in September 2010.

The IMC established a Technical Committee, co-chaired by the Directors-General of Mineral Resources and Water Affairs, which instructed a Team of Experts to prepare a report advising the IMC on solutions to control and manage AMD in the Witwatersrand goldfields. In February 2011, Cabinet considered the IMC report and instructed that the recommendations be implemented as a matter of urgency. Funds were then allocated to the Department of Water Affairs (DWA) by National Treasury with the purpose of implementing some of the IMC recommendations, namely to:

- Investigate and implement measures to pump the underground mine water in order to prevent the violation of the Environmental Critical Levels (ECLs), *i.e.* specific underground levels in each mining basin above which mine water should not be allowed to rise so as to prevent adverse environmental, social and economic impacts;
- Investigate and implement measures to neutralise AMD (pH correction and removal of heavy metals from AMD); and
- Initiate a Feasibility Study to address the medium- to long-term solution.

The investigations and implementation actions proposed in the first two recommendations commenced in April 2011, when the Minister of Water and Environmental Affairs issued a Directive to the Trans-Caledon Tunnel Authority (TCTA) to undertake “Emergency Works Water Management on the Witwatersrand Gold fields with special emphasis on AMD”:

When the proposed pumping and neutralisation commences in the Central and Eastern Basins the situation will be similar to that which prevailed when underground mining and dewatering of the mine voids, and partial treatment of the water, were being carried out by the active mining companies. The saline AMD will flow into the Vaal River System and specifically into the Vaal Barrage. The high salt load will have the same impact on the Vaal River System as described earlier.

The third recommendation resulted in the Terms of Reference (ToR) for this Feasibility Study (DWA 2011a) being issued in July 2011. The ToR noted that the IMC had recommended that a Feasibility Study should be initiated as soon as possible, since the Short-Term Interventions (STI) might influence the roll-out of the desired medium- to long-term solution.

In January 2012, DWA commissioned the Feasibility Study for the Long-Term Solution (LTS). The Study period was 18 months, with completion at the end of July 2013. It was emphasised that this Study was very urgent, would be in the public eye, and that recommendations to support informed decision-making by DWA were required. The recommended solution must support the Water Resource Strategies for the Vaal and Crocodile West River Systems and take account of the costs, social and environmental implications and public reaction to the various possible solutions.

The urgency of reducing salt loading on the Vaal River System and the relatively short study period for such a complex study means that implementation decisions have to be based on the current understanding of the best available information and technical analyses that have been completed by the time the decisions must be made. Thus, a precautionary and conservative approach was adopted during the Study.

Opportunities have been identified where the solutions that are implemented can be refined, during operation, as more information becomes available.

2. Integration with the Short-Term Intervention

The final TCTA Due Diligence Report (TCTA, 2011) was submitted to DWA in August 2011, and tenders for construction in all the basins were invited in November 2011. Immediate works were implemented in the Western Basin in 2012, and construction in the Central Basin commenced in January 2013. It is anticipated that construction of the Eastern Basin will commence in the first quarter of 2014.

The Scope of Work (SoW) of this Feasibility Study, with respect to the STI, is to understand the proposed STI in sufficient detail to:

- Undertake a Feasibility Study of all options, irrespective of the STI, in the interests of finding the best LTS;
- Determine how to integrate the STI and LTS, and influence the STI as far as appropriate or practical;
- Identify any potential long-term risks associated with the proposed STI, and propose prevention or mitigation measures; and
- Assess the implications of the proposed STI for the suggested institutional model for the implementation, operation, maintenance and/or management of the preferred LTS.

3. Approach to the Study

The focus areas of the Feasibility Study comprise technical, legal, institutional, financial/economic and environmental assessments, as well as public communication and key stakeholder engagement. The Feasibility Study comprises three phases; the Initiation, Prefeasibility and Feasibility Phases. The main components and key deliverables of each phase are shown in **Figure 1**, and each phase is discussed in more detail below.

The technical assessments run in parallel with the legal assessment, and both feed into the options assessment. The component on stakeholder engagement and communication was started early in the Study so that a stakeholder engagement and public communication strategy could be developed as soon as possible and be implemented throughout the Study.

The planning showed the Feasibility Phase as following the Prefeasibility Phase, but the short study period meant that it was necessary for the Feasibility Phase components to commence during the Prefeasibility Phase and run in parallel.

In conducting the Study, it was important that each component developed key information and recommendations, which were then used in subsequent components. The logical and timeous flow of information and recommendations was essential in order to develop solutions and meet the Study programme.

Figure 2 gives an overview of the technical, institutional/financial and implementation components and the flow of information throughout the Study. It can be seen how the fixed information (*e.g.* ECLs, raw water quality, ingress, *etc.*) and the decisions to be made, or the options to be investigated (*e.g.* abstraction points, qualities and quantities required by potential users, locations of users, treatment technologies) feed into the options assessment and identification of the Reference Project. The Reference Project will define the option that uses proven technologies, has the least associated risk, and is used for financial modelling and budgeting. It will probably not be the same as the option that is implemented, but constitutes the benchmark against which implementation proposals will be judged.

The Concept Design is based on the Reference Project and includes the costing and land requirements. This in turn provides input for the evaluation of the institutional procurement and financing options and the Implementation Strategy and Action Plan.

The phases of the Study, the key components and their inter-relationships are described below and illustrated in **Figures 1 and 2**.

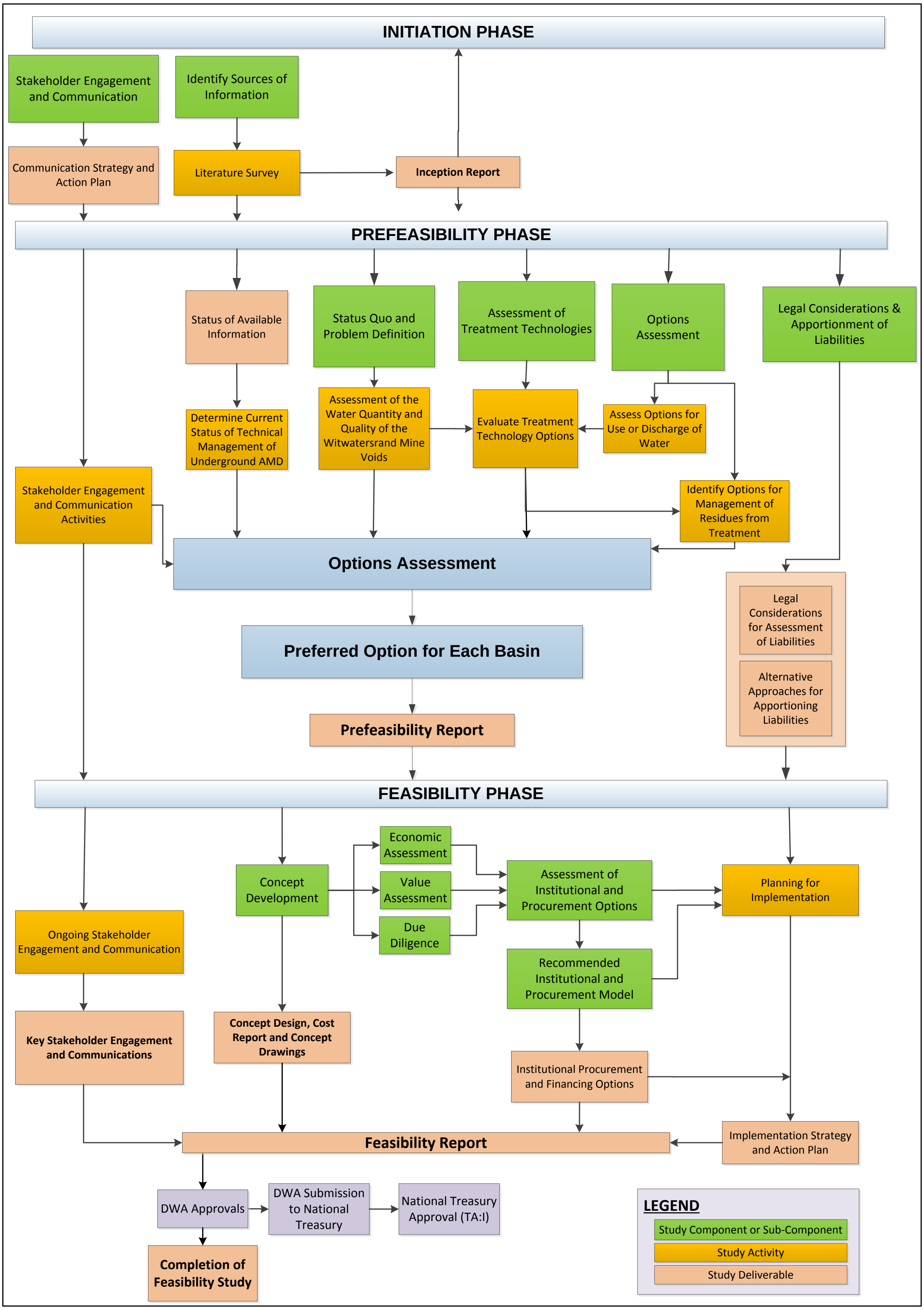

Figure 1: Study phases and components

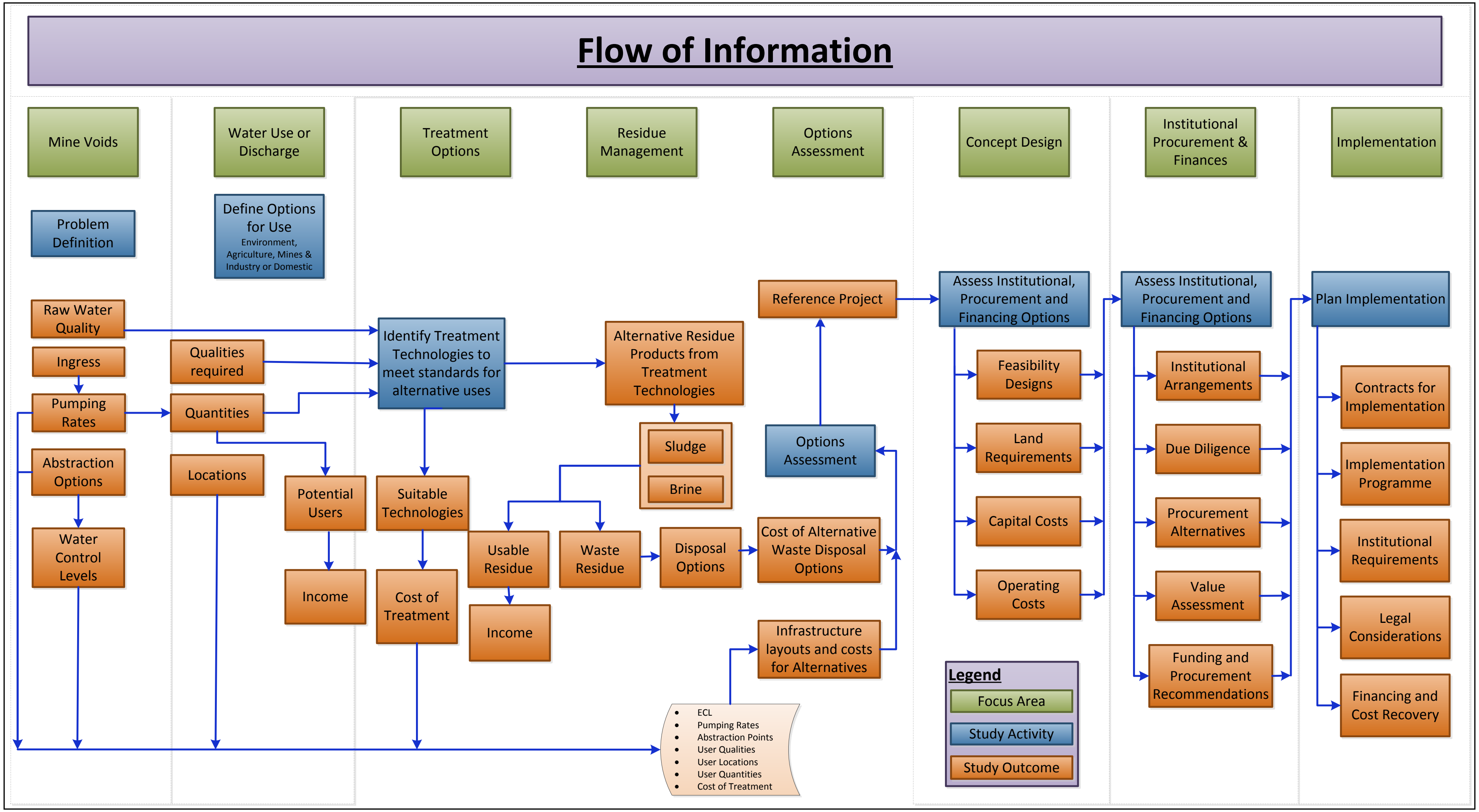

Figure 2: Flow of information throughout the Study

PHASE 1: Initiation

The objective of the Initiation Phase was to determine the approach and principles for the Study and understand the work already done by others. Numerous reports from previous studies, maps and research findings, relating to all components of the Study, were collated and reviewed. The SoW, proposed approach and the study programme were reviewed after initial consideration of the available information. The study objectives and priorities were reviewed and the results are presented in Study Report No. 1: ***"Inception Report"***.

The results of the complete literature survey, which continued after the Initiation Phase, are presented in Study Report No. 2: ***"Status of Available Information"***.

The Study Report No. 9.1: ***"Communication Strategy and Action Plan"*** was prepared so that key stakeholder engagement and communicators could commence as soon as possible and continue throughout the Study.

PHASE 2: Prefeasibility

The purpose of this phase was to understand and describe the current status and the environment for managing AMD and then to identify all apparently viable alternative solutions and, from those, identify the more feasible options, on the basis of technical feasibility, social and environmental acceptability and cost effectiveness. These were then considered in more detail, and the most feasible options were investigated in the Feasibility Phase.

The assessment of the legal liabilities and mechanisms for the apportionment of liabilities is a key stand-alone component that was commenced in the Prefeasibility Phase and finalised in the Feasibility Phase. This work is described in the confidential Study Report No. 3: ***"Legal Considerations for Apportionment of Liabilities"*** and confidential Study Report No. 4: ***"Alternative Approaches for Apportioning Liabilities"***.

The objectives of the Prefeasibility Phase were to:

- Understand the status quo;
- Define the problem;
- Understand the quantity and quality of water in the mine voids and how fast is it rising in each basin;
- Identify possible uses for the water;
- Identify treatment technologies that can treat the necessary volumes of AMD to the standard required by various users;
- Understand the residues (or waste products) produced by each process and how they can be managed;
- Define a wide range of options for possible solutions by combining alternatives for abstraction, water use, treatment and management of residues;
- Screen the alternatives to identify viable options; and

- Carry out prefeasibility costing of the most viable options and identify the most appropriate option to be used as the Reference Project.

To achieve these objectives, the Prefeasibility Phase needed to provide the team with:

i. A sound understanding of the STI, how it can be integrated into the LTS, and the impact of the STI on the selection and procurement of the LTS. This is described in Study Report No. 5.1: ***"Current Status of Technical Management of Underground AMD"***.

ii. A sound understanding of the hydrogeology, underground water resources, sources of surface water ingress, spatial distribution and connectivity of mined voids; and the current water quality and projections of future volumes, levels and water qualities. This was based on the substantial information from previous studies and is presented in Study Report No. 5.2: ***"Assessment of the Water Quantity and Quality of the Witwatersrand Mine Voids"***.

iii. An understanding of the DWA Water Resource Management Strategies for the Vaal River System and Crocodile West River System. These strategies provided the framework within which to develop a range of possibilities for the use or discharge of raw, neutralised or desalinated AMD to meet the objective of reducing the salt load in the Vaal River System and associated catchments to acceptable levels without having an unacceptable social or environmental impact. These possibilities are described in Study Report No. 5.3: ***"Options for Use or Discharge of Water"***.

iv. An assessment of suitable technologies for treating either raw AMD or the discharges from the STI to standards that will not negatively impact on the environment and will be acceptable to a range of users. This assessment is described in Study Report No. 5.4: ***"Treatment Technology Options"***.

v. Locality plans for the possible disposal of waste, or potential uses for residue products generated by treatment processes. These plans are described in Study Report No. 5.5: ***"Options for the Sustainable Management and Use of Residue Products from the Treatment of AMD"***.

The knowledge and data from the Prefeasibility Phase were used to combine the alternative locations for the abstraction, treatment and use or discharge of water and the disposal of waste, as well as the layouts of the infrastructure required (including pipelines and pump stations), into a large number of options. The alternatives were screened at a high level to give a short-list of practical technical options.

The capital and operating costs of the short-listed options were determined to give a present value of lifetime cost. Social and environmental screening for fatal flaws was carried out, and possible financial benefits from the sale of water or waste were considered. The anticipated public reaction to the options was also considered. The identification of the Reference Project was then completed on the basis of the costs, benefits and impacts. The costs and implications of possible alternatives were also defined. The results and an overview of all the components of this Prefeasibility Phase are described in Study Report No. 5: ***“Technical Prefeasibility Report”***.

PHASE 3: Feasibility

The main objective of this phase was to carry out intensive feasibility level investigations and optimisation of the most feasible layouts for each basin and to select a preferred option to be used as a Reference Project for each basin. The requirements for implementation were also considered and evaluated.

The Feasibility Phase comprises a number of components that build on the results of the Prefeasibility Phase; the results of the various components are reported separately and then integrated in a Feasibility Report for the solution to AMD.

The components in this Phase comprise:

i. Concept Development:

   Once the Reference Project for each basin had been agreed, the layout for the treatment works, pipelines and waste storage and disposal sites was planned and costed. Environmental screening was undertaken for each of the identified sites that form part of the Reference Project. The results are presented in the confidential Study Report No. 6: ***“Concept Design”***, the confidential Study Report No. 6.1: ***“Concept Design: Drawings”*** and the confidential Study Report No. 6.2: ***“Concept Design: Costing”***.

ii. Institutional Procurement and Financing Options:

   The following alternative procurement models for implementation were evaluated:

   - a ‘traditional’ Government-funded and a traditionally procured Employer Design, Procure, Construct and Operate solution, which is the Public Sector Comparator model (PSC);
   - a Design, Build, Operate and Maintain (DBOM) scenario funded by an Implementing Agent, using Private Sector or Government funding, which is also a Public Sector Comparator model (PSC); and
   - a private sector-funded Public–Private Partnership (PPP).

   The approach included a detailed risk-adjusted value assessment of the PSC and PPP models for the Reference Project in each of the three basins. The possible institutional arrangements were assessed in terms of the roles and responsibilities of the responsible organisations.

   A due diligence assessment was carried out to establish the legal mandates of the institutions, as well as ownership of the land required for the Reference Project. These assessments are described in the confidential Study Report No. 7: ***“Institutional, Procurement and Financing Options”***.

iii. Implementation Strategy and Action Plan:

Throughout the Study, the requirements for implementation were considered in developing an Implementation Plan. Where necessary, the activities required for implementation that must commence in parallel with this Study were identified. This included the preparation of a Request for Information (RfI), which initiated a process through which service providers could register their interest with DWA. All the requirements for implementation are described in Study Report No. 8: ***"Implementation Strategy and Action Plan"***.

iv. Key Stakeholder Engagement and Public Communication:

Engagement with key stakeholders and public communication were very important components of the Study and were on-going from the commencement of the Study to the completion of the work. Study Stakeholder Committee meetings, Focus Group meetings, a RfI, one-on-one meetings, newsletters and a website were key elements. The process and results are presented in Study Report No. 9: "***Key Stakeholder Engagement and Communications***".

The final deliverable, Study Report No. 10: ***"Feasibility Report",*** summarises the results of the Study.

The Prefeasibility Phase and Concept Development in the Feasibility Phase are typical components of many planning studies. Solving the technical issues is not normally the biggest challenge, although this project does have several unique aspects. However, the Feasibility Phase components that lead to recommendations for appropriate institutional, financial and procurement models for implementation, particularly the assessment of the options for procurement, are not common components of DWA studies and were the most challenging, and certainly as important for a sustainable solution as all the technical components combined.

4. Way Forward

Completion of the Study will provide all the information required for implementation to proceed, although DWA plans to start the preparations required for implementation in parallel with Phase 3 of this Study.

Following from the Feasibility Study, implementation should be carried out as soon as possible. The key activities required for implementation include the following:

- DWA submitting the Feasibility Study Reports to National Treasury for their review and approval. The project has been registered with National Treasury, and Treasury Approval 1 (TA 1) may be required before procurement can commence;
- Conducting an Environmental Impact Assessment (EIA); and
- The preparation of procurement documents.

If procurement is for a Design, Build, Operate and Maintain (DBOM) contract, the procurement documents will comprise:

- A Request for Qualifications (RfQ) to allow DWA to short-list suitably qualified service providers.

  This will allow any service provider, especially those with proprietary technologies that may well be more cost effective than that used as the reference technology, to submit detailed information. Those that best meet the selection criteria, which will have to be agreed, will be short-listed; and
- A Request for Proposals (RfP) to be issued to the short-listed service providers, inviting them to submit tenders to implement a project that will deliver water to the specified standards.

If procurement is to follow the traditional process (with three sequential tenders for a service provider to prepare design and tender documentation, followed by tenders for construction, and then tenders for operation and maintenance), then the two-phase RfQ and RfP route may also be followed, with appropriate requirements specified at each stage.

The Reference Project could be implemented, but may not be the most effective solution. It will provide the yardstick methodology and costing which will be used to evaluate the tenders which are submitted.

DWA will also need to source the technical and contractual expertise required to enable them to manage the implementation of the desired long-term solution in each of the three basins.

NOTE: A List of Acronyms and Glossary of Terms appear on pages “xxx” and “xxxiv” respectively.

APPROVAL

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David Sislen	World Bank
Marcus Wishart	World Bank

In addition to the contributions received from the study committees mentioned above, inputs were also received from the following broad groups and sectors through focused discussions (a more comprehensive list is available on the DWA AMD website):

Academic institutions;
Funding organisations;
Global perspectives on AMD management;
Environmental and conservation groups;
Independent individuals in their private capacity;
Institutions, parastatals and research facilities;
Local, provincial and national government;
Mining sector;
Non-governmental organisations;
Organised agriculture;
Organised business, industry and labour;
Other specialist fields/consultants;
Tourism and recreation;
Utilities/water service providers; and
Various technology providers who offered information.

Organisations that provided considerable data and inputs for assessment and consideration, including the but not limited to, FSE, The Centre for Environmental Rights, Sasol, DST, WRC, Ekhuruleni Municipality, Rand Water, GDARD, DEA, CGS, DMR as well as various individuals in their private capacity, are thanked for their contributions.

WISA Mine Water Division, a division of the Water Institute of Southern Africa, agreed to peer review selected key reports from the Feasibility Study for the Department of Water Affairs. The Division offered to identify and carry the cost of the appointment of the independent external experts. The assistance of WISA Mine Water Division and the inputs from their experts are duly appreciated and acknowledged. The comments and suggestions by the following experts contributed significantly to the quality of the study: Achim Wurster (Private Consultant), Ingrid Dennis (North-West University), André van Niekerk (Golder and Associates) and Phil Hobbs (CSIR).

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Aurecon South Africa (Pty) Ltd;
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Ledwaba Mazwai Attorneys;
IGNIS Project & Finance Solutions (Pty) Ltd;
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Various independent consultants, not mentioned separately.

EXECUTIVE SUMMARY

The options for the use or discharge of water derived from the management of Acid Mine Drainage (AMD) must be evaluated against the backdrop of the river system reconciliation strategies for the Vaal, Olifants and Crocodile West River Systems.

The local surface water resources for the Vaal and Crocodile West Water Management Areas (WMAs) have been fully exploited for more than three decades. The Vaal River System supplies water to about 60% of the South African economy and 45% of the population. It is therefore crucial to conduct proper planning for the future and optimise the use of the available resources to ensure that all demands are satisfied.

The yield of the Vaal River System will reduce from 2014 onwards due to releases that will be required to dilute the Vaal River water to an acceptable quality if the AMD-related salinity is not addressed. Even with the earliest introduction of the second phase of the Lesotho Highlands Water Project, the Polihali Dam in about 2020, there will still be deficits, which could have enormous economic implications.

The strategies to be implemented as part of the Vaal River Strategy to match the supply and demand more closely are as follows:

- *Eradicate unlawful water use, which will reduce the water requirement. The strategy takes into account that there may be some of the original perceived unlawful use that will turn out to be lawful. To allow for this it is assumed that only 85% of the original perceived unlawful use will be eradicated.*
- *Implement water conservation and water demand management in the major urban centres to reduce water use by 15%; and*
- *Address the AMD-related salinity to sustain the current system yield into the future.*

Successful implementation of all these strategies is necessary to maintain a positive water balance until 2050 and beyond. The Polihali Dam yield is also included, on top of the scenario where AMD-related salinity is managed. The uncertainties in achieving a scenario where no deficits occur are immense, and failure to implement any of the strategies successfully could result in deficits.

One of the Feasibility Study's deliverables is an Economic Assessment of the long-term solution that will be proposed to investigate the economics of the project. The economic analysis will assess the cost benefit and the macro-economic impact of implementing the LTS for the AMD against other scenarios. For all scenarios the proposed STI to neutralise the AMD, with some reduction in salinity, is assumed to be implemented. The scenarios are:

- ***Scenario 1: Do Nothing** - For this scenario no dilution releases will be made from the Vaal Dam and there will be no reduction in the salinity of the AMD through any treatment after the neutralisation.*
- ***Scenario 2A: Dilution without early implementation of the Thukela Water Project –** For this scenario, once neutralised AMD is released into the river system continuous*

dilution releases from Vaal Dam will be made to maintain the interim Resource Water Quality Objective (RWQO) of 600 mg/ℓ for TDS in the Vaal Barrage and downstream. The Thukela Water Project (TWP) will not be commissioned until required for normal augmentation (as if dilution releases had not been made) and this will be after 2050.

- ***Scenario 2B: Dilution with Thukela Water Project Implemented -*** *This scenario will be analysed with the TWP commissioned in 2025 to augment the Vaal River System and continuous dilution releases made from Vaal Dam in order to maintain the interim RWQO of 600 mg/ℓ for TDS in the Vaal Barrage.*
- ***Scenario 3: Long-term Solution for AMD -*** *For this scenario, the AMD generated in the Central and Eastern Basins will be neutralised and the salts that are released into the Vaal River System will be reduced. The AMD salt loading will also be reduced in the Western Basin but the AMD discharges do not flow into the Vaal River System, but into the Crocodile (West) River System.*

General re-use options for treated AMD were identified, including options in the domestic, industrial and agricultural sectors. A summary of the general re-use options are shown in the ***Table 1*** *below.*

The water users in the Witwatersrand region that could potentially be users of treated AMD were identified. The main bulk buyer and supplier of water in the region is Rand Water, which supplies about 4 100 Mℓ/d of water to approximately 12 million people. Rand Water buys its raw water from the Department of Water Affairs (DWA) and draws it from the Vaal Dam, (supplied by the Lesotho Highland scheme), and the Sterkfontein and Grootdraai Dams.

Rand Water's municipal customers account for almost 92% (3 767 Mℓ/d) of total demand, with mining customers adding more than 6% (246 Mℓ/d) and industries about 1% (41 Mℓ/d), and all other direct customers accounting for the balance.

Rand Water has indicated that they have received applications from industrial users for water supply. Rand Water also indicated that they currently do not have enough water to supply these industrial users and that treated AMD might be well suited to answer this demand. Besides the 41 Mℓ/d that is supplied directly to industrial users, there are also industries that are supplied via the municipal network.

The supply of AMD, whether untreated, partially treated or desalinated, to mining customers only provides an interim solution, as supply is linked to the life of the mine and thus not necessarily a Long-Term Solution (LTS).

Table 1: Categories of re-use; examples of applications; potential for AMD; and risk in re-use

Industry	***Mining***	***Urban / Domestic***	***Agriculture***
Cooling water: *Ash quenching* *Process waters:* *Transport agent* *Utility water:* *Dust suppression* *Fire fighting* *Wash water:* *Wash water for rough washing (floors, rough apparatus, trucks, raw materials)* ***Conclusion*** *The potential within the vicinity of AMD abstraction and treatment locations needs to be investigated* *Risk of salt load returning to water resources when inappropriately controlled*	*Cooling water:* *Ash quenching* *Process waters:* *Transport agent* *Utility water:* *Dust suppression* *Fire fighting* *Wash water:* *Wash water for rough washing (floors, rough apparatus, trucks, raw materials)* *Some mine re-use potential within the vicinity of AMD abstraction and treatment locations. This may accommodate 20-50% of the AMD on a basin by basin basis, but may not be a long-term demand as such ore resources themselves become exhausted in the short to medium term* ***Conclusion*** *Risk of salt load returning to water resources when inappropriately controlled.* *Risk of increased water use infrastructure corrosion and erosion due to salt content*	*Unrestricted landscape irrigation of parks, playgrounds, school yards, golf courses, cemeteries, residential, green belts* *Restricted irrigation of areas with infrequent and controlled access* *Other fire protection, disaster preparedness, and construction* *Domestic water uses not requiring potable water quality, e.g. toilet flushing.* *Most suited to new recreational developments as conveying water will require a separate pipeline* ***Conclusion*** *Portion of salt retained in soil (effectiveness as salt sink) will depend on water composition and how well leaching is minimised through proper water application management* *Risk of water use increased infrastructure corrosion and erosion due to salt content*	*Food crops irrigation for crops grown for human consumption* *Non-food crops and crops consumed after processing* *Irrigation for fodder, fibre, flowers, seed crops, pastures, commercial nurseries, and instant lawn* ***Conclusion*** *Availability of suitable land need to be investigated* *Portion of salt retained in soil (effectiveness as salt sink) will depend on water composition and how well leaching is minimised through proper water application management, but salt load will not necessarily be removed from the system, and may accumulate in soil and groundwater systems over time* *Risk of increased water use infrastructure corrosion and erosion due to salt content*

Rand Water’s Water Demand Projection Study (Rand Water, 2009) projected growth of 2.14% in potable water demand up until 2025. Rand Water has current rights to abstract 3 688 Mℓ/d of raw water from the Vaal River Government Scheme, which includes the Vaal Dam. The volume will not be adequate to supply the growth in water demand, and Rand Water is therefore applying to increase the abstraction volumes on the basis of the projected volume of raw water needed to supply consumers.

The following remote industrial users were identified that receive comparable volumes of water from the Vaal River System:

- *Eskom, which currently operates 12 coal-fired power stations, with three more being planned. The water requirement scenario that was used in the planning analysis indicated that the total water demand for all the power stations is expected to increase from 313 million m^3/a (858 Mℓ/d) in 2006 to 397 million m^3/a (1 088 Mℓ/d) in 2030.*
- *Sasol has two plants receiving water from the Integrated Vaal River System. The Sasol Synfuels facility (Secunda) uses approximately 230 Mℓ/d of raw water from the Vaal River system as well as 25 Mℓ/d of treated water from the Rand Water supply system, thus 255 Mℓ/d in total. The Sasol Infrachem facility (Sasolburg) uses approximately 60 Mℓ/d from the Vaal Dam. The total use by Sasol of 315 Mℓ/d (115 million m3/a) is expected to increase to 455 Mℓ/d (166 million m3/a) by 2030.*
- *Mittal Steel, which receives its water from the Vaal Dam via Rand Water. In terms of their projections Mittal Steel was planning to decrease its current water use from 17.4 million m^3/a (47.7 Mℓ/d) in 2006 to 16.6 million m^3/a (45.5 Mℓ/d) in 2010, after which the water use was projected to remain constant for the remaining years of the planning period.*

The water requirements for irrigation comprise about 35% of the total water use of the Vaal River System. The Vaalharts Irrigation Scheme, the largest in the country, uses 31% of this sector's water. Due to the strategic decision that any new water use will have to pay the full Vaal River tariff, irrigation water use is considered likely to remain constant.

It must be emphasised while the quantity of AMD from all three basins is not very significant as a resource in the Vaal River System, it is still important and should be used. However, the volume of the dilution releases required to curb the effect of the AMD related salt loading is very significant and will threaten the supply security. It is estimated that these dilution releases can lead to a reduction in the yield of the Vaal River System of up to 500 million m^3/a.

In a South African context, the term 'salt loading' is used to collectively refer to certain chemical constituents in solution (e.g. Calcium, chloride, magnesium, sodium, sulphate, etc.), whereas the term used by the International Mine Water Association is 'mineralisation'. The term 'salt loading' is used throughout all reports for this Feasibility Study. To allow comparison with the figures given above, the quantities of AMD that can be expected from each basin are given in ***Table 2****.*

Table 2: Proposed Pump Rates

Basin	***Approximate. Abstraction Rates (Mℓ/24hrs)****	
	Average Rate	***Range***
Western	*23*	*19 – 27*
Central	*46*	*30 – 90*
Eastern	*80*	*70 – 100*

**Study Report No. 5.2*

The typical water qualities of the AMD that can be expected from each of the three basins are shown in ***Table 3****.*

Table 3: 95th percentile raw AMD qualities

Parameter	***Unit***	***Basin****		
		Western	***Central***	***Eastern***
pH	*@ 25°C*	*3.5*	*2.4*	*5.9*
Total dissolved solids	*mg/ℓ*	*5 434*	*4 592*	*3 358*
Electrical conductivity	*(mS/m) @ 25°C*	*442*	*465*	*363*
Ca	*mg/ℓ*	*703*	*563*	*421*
Mg	*mg/ℓ*	*-*	*258*	*166*
Na	*mg/ℓ*	*227*	*171*	*264*
SO_4	*mg/ℓ*	*3 623*	*3 062*	*2 289*
Cl	*mg/ℓ*	*-*	*146*	*254*
Acidity/Alkalinity	*mg/ℓ*	*1 520*	*-*	*560*
Fe	*mg/ℓ*	*954*	*108*	*227*
Al	*mg/ℓ*	*-*	*193*	*2.4*
Mn	*mg/ℓ*	*89*	*50*	*5.9*
U	*mg/ℓ*	*-*	*0.695*	*0.470*

**DWA AMD FS 2013, Study Report No. 5.2 – Table 10.5*

In considering the supply of raw AMD to consumers, only one possible alternative was identified and assessed as far as the available information allowed. Mintails, which operates a gold recovery process in the vicinity of Rand Uranium No. 8 Shaft in the Western Basin, has developed a process of neutralising AMD with the wastewater being generated in the gold recovery process. This process is a very recent development of which the study team was made aware only in September 2012. The STI Team has been tasked to engage with Mintails and investigated their process in more detail.

It would be unacceptable to supply raw AMD for any potable purposes, or to discharge raw AMD to the environment. If this were allowed to happen, then this study, as well as the STI, would altogether fail to achieve its objectives, since the AMD would not have been neutralised; no metals would have been removed; and the high salt-loading would still be present.

The use or discharge of neutralised AMD, although also attractive because of the expected low costs, would still pose substantial risks to the surface and underground water resources in the study area as well as the downstream users and environment. Neutralised AMD would still have a very high salt load, and there is no assurance that the salts would be reduced to *acceptable levels before release to the environment and/ or discharge to the river. This would pose a direct risk to achieving the study goal of ensuring long-term water supply security and continual fitness for use of the Vaal River and Crocodile (West) River water by removing the salinity.*

Past research has indicated that neutralised AMD can be used for agriculture in the short-to-medium-term. Such irrigation has to be properly managed and should only be practised on areas where the soil properties match the requirements.

Desalinated AMD was considered for supply to domestic and local and remote industrial users, as well as discharge to the environment.

From the outset of this study, it has been understood that Rand Water will be a key stakeholder in utilising the treated AMD and also with implementation of the recommended LTS. Discussions with Rand Water regarding the supply of desalinated AMD for domestic or industrial use were initiated during 2012. Rand Water indicated early on that they are not in favour of supplying any treated AMD to domestic users, since they are wary of the negative public perception that might result if such water is introduced into their system. Thus, only the option of ***industrial use was investigated in further detail and recommended for the Reference Project****, although it is believed that potable quality water can be guaranteed, should it be decided to use treated AMD to augment domestic supplies.*

Discharge to the environment has been extensively evaluated and will be acceptable from a purely environmental perspective. However, this option will be far less economically viable than other options since no revenue will be generated from the sale of treated AMD. The proposed discharge points if discharge to the environment needs to occur for short periods of time have been identified as:

- *Western Basin - Treated AMD could be rerouted to the Percy Stewart Waste Water Treatment Works and discharged with the treated waste water at a less sensitive point in the Bloubank Spruit.*
- *Central Basin - Treated water could be discharged downstream of the wetland in the Elsburg Spruit.*
- *Eastern Basin - Discharge of treated water could occur downstream of the Marievale Bird Sanctuary.*

The water qualities required by Rand Water, Sasol and the environment compared against the SANS 241 limits (Acute Health and Aesthetic) and the water quality in Vaal Dam (the latest annual information) are summarised in ***Table 4****:*

Table 4: Summary of required water qualities

	Chlorides (mg/ℓ)	***Sulphates (mg/ℓ)***	***TDS (mg/ℓ)***
SANS 241 : Acute Health[1] *Aesthetic*[2]	*-* *300*	*500* *250*	*-* *1 200*
Environment RWQO:			
Western Basin (Tweelopies Spruit)	*75*	*400*	*481*
Central Basin (Klip River) (Low/high)	*50/75*	*200/350*	*520/650*
Eastern Basin (Blesbokspruit) (Low/high)	*80/150*	*150/300*	*293/455*
Rand Water[3]	*9 – 13*	*13 – 17*	*130 – 230*
Sasol: Cooling water - current			*150*
Cooling water - preferred			*40*
Boiler Feed Water			*0.1 – 1*
Vaal Dam at Rand Water intake[4, 5]			
1/10/2012 – 31/12/2012	*< 10*	*21*	*208*
1/01/2013 – 31/03/2013	*< 10*	*24*	*143*
1/04/2013 – 30/06/2013	*< 10*	*22*	*137*
1/07/2013 – 30/09/2013	*< 10*	*21*	*130*

1 Poses an immediate unacceptable health risk if consumed
2 Taints water with respect to taste, odour and colour and that does not pose an unacceptable health risk
3 From Rand Water website for period 22 June to 22 July 2011 (Average ± 3 standard deviations). Water supplied to Johannesburg Metropolitan Municipality. Assumes that industrial customers are supplied via the same network.
4 http://www.reservoir.co.za/forums/vaaldam/vaaldam_forum/vaaldam_chemical_2013/RW_vaaldam_jul-sep2013.pdf
5 TDS values calculated from Conductivity using a conversion factor of 6.5 to convert from mS/m to mg/ℓ.

In terms of salinity, TDS and sulphate concentrations will need to be better than the SANS 241 requirement to be comparable with Rand Water quality water and to suitably address salt-loading to be caused by the underground mine water, and may therefore have to equate to the Vaal Dam quality. A TDS concentration of 200 mg/ℓ was used in the modelling runs for the preferred scenario which excluded salt-loading from underground mine water.

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Appendix B: Summary of Target Water Quality Ranges for Different Water Use Sectors

LIST OF ACRONYMS

ADD	Average Delay Demand
Alk	Alkalinity
AEV	Acute Effect Value
AMD	Acid mine drainage
CAPEX	Capital expenditure
Cat	Category
CBEC	Central Basin Environmental Corporation
CEV	Chronic Effect Value
CGS	Council for Geoscience
Chl-a	Chlorophyll a
COD	Chemical Oxygen Demand
Cond	Conductivity
COO	Chief Operations Officer
CRG	Central Rand Gold
CSIR	Council for Scientific and Industrial Research
DST	Department of Science and Technology
DMR	Department of Mineral Resources
DRD	Durban Roodepoort Deep
DWA	Department of Water Affairs (since 2009)
DWAF	Department of Water Affairs and Forestry (until 2009)
EBEC	Eastern Basin Environmental Corporation
EC	Electrical conductivity
ECL	Environmental critical level
EI	Ecological importance
EIA	Environmental Impact Assessment
EI&S	Ecological importance and sensitivity
ERPM	East Rand Proprietary Mines
FAO	United Nations Food and Agriculture Organisation
GDARD	Gauteng Department of Agriculture and Rural Development
GDP	Gross domestic product
GEC	Global Environment Centre Foundation
HDS	High Density Sludge
HP	High pressure
IMC	Inter-Ministerial Committee
ISP	Internal Strategic Perspective

IWQMS	Integrated Water Quality Management Strategy
IWRM	Integrated water resource management
LP	Low pressure
LTS	Long-Term Solution
MPRDA (28:2002)	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)
NATSURV	National Survey of Industrial Water and Wastewater
NEDLAC	National Economic Development and Labour Council
NEMA (107:1998)	National Environmental Management Act (Act No. 107 of 1998)
NGO	Non-government organisation
NWA (36:1998)	National Water Act, 1998 (Act No. 36 of 1998)
NWRS	National Water Resource Strategy
OPEX	Operating Expenditure
PES	Present ecological state
PPP	Public–Private Partnership
PSC	Public Sector Comparator
PSD	Peak Service Demand
PSP	Professional Service Provider
RDM	Resource Directed Measures
RQO	Resource quality objectives
RWQO	Resource water quality objectives
SA	South Africa
SAC	Study Administration Committee
SALGA	South African Local Government Association
SANS	South African National Standards
SAR	Sodium adsorption ratio
SMC	Study Management Committee
SoW	Scope of Work
SRK	SRK Consulting (Pty) Ltd
SSC	Study Stakeholder Committee
STI	Short-term intervention
STS	Short-Term Solution
SWB Model	Soil Water Balance Computer Model
TA 1	Treasury Approval 1
TCTA	Trans-Caledon Tunnel Authority
TDS	Total dissolved solids
TIA	Technology Innovation Agency of South Africa
TSS	Total suspended solids
TWT	Tailings Water Treatment

TWP	Thukela Water Project
TWQR	Target Water Quality Range
UNEP	United Nations Environmental Programme
WBEC	Western Basin Environmental Corporation
WISA	Water Institute of Southern Africa
WMA	Water management area
WRC	Water Research Commission
WUC	Western Utilities Corporation (Pty) Ltd
WWTW	Waste Water Treatment Works

LIST OF CHEMICAL CONSTITUENTS

Al	Aluminium
Ca	Calcium
Ca^{2+}	Ionic Calcium Solution
$CaCO_3$	Calcium Carbonate
Cl	Chloride
F	Fluoride
Fe	Iron
Mg	Magnesium
Mg^{2+}	Ionic Magnesium Solution
Mn	Manganese
N	Nitrogen
Na	Sodium
NH_4	Ammonia
NO_3	Nitrate
O_2	Dissolved Oxygen
P	Phosphate
PO_4	Phosphate
SiO_2	Silicon Dioxide
SO_4	Sulphate
TH	Total Hardness
TN	Total nitrogen
TP	Total phosphorus

UNITS OF MEASUREMENT

µg	microgram
a	annum
C	Celsius
cm	centimetre
d	day
dS	decisiemen
ha	hectare
km	kilometre
km^2	square kilometre
ℓ	litre
m	metre
m^3	cubic metre
mg	milligram
Mℓ	megalitre
mm	millimetre
mmho	milli-mho
mS	millisiemen
ppm	parts per million

GLOSSARY OF TERMS

Adit	An adit is an entrance to an underground mine which is horizontal or nearly horizontal, by which the mine can be entered, drained of water, and ventilated.
AMD	Acid mine drainage is formed when sulphide minerals in the geological strata, are exposed through mining activities and interact with oxygen and water to form a dilute solution of sulphuric acid and iron that leaches other metals from the material in which it forms. Acid mine drainage in the Witwatersrand typically has a pH value around 3 and is enriched in sulphate, iron and a number of metals, often including uranium.
Annexure	Documents produced by others attached to the report.
Aquifer	Zone below the surface capable of holding groundwater.
Avulsion	The rapid abandonment of a river channel and the formation of a new river channel. Avulsions occur as a result of channel slopes that are much lower than the slope that the river could travel if it took a new course.
Central Basin	Central Rand underground mining basin.
Catchment Vision	The visioning process enables the DWA to formulate an initial statement (*i.e.* the catchment vision) about a desired future state of the water resource on behalf of the catchment community and other interested parties
Decant (surface)	Spontaneous surface discharge of water from underground mine workings.
Decant (subsurface)	Subsurface flow of water from one mine compartment or geological structure to another, typically occurring when underground mine voids fill and cascade consecutively from one underground compartment to another adjacent connected compartment.
Eastern Basin	East Rand underground mining basin.
Environmental Critical Level	The level above which the water in the mine voids at the critical locations (that is where the environmental features to be protected are at the lowest elevations) should not be allowed to rise, to protect specific environmental features, including groundwater resources.
Fault	Crack in the earth along which differential movement of the rock mass has occurred.
Feasibility Study	An analysis and evaluation of a proposed project to determine if it is technically sound, socially acceptable, and economically and environmentally sustainable.
Freeboard	The vertical distance below the Socio Economic or Environmental Critical Level at the abstraction point, below which the water level should generally be maintained, to allow for hydraulic gradient across the basin, seasonal peak ingress, pump down time, and the like, *i.e.* to provide sufficient buffer capacity.
Groundwater	Water occupying openings below surface

Gypsiferous Water	Water that is dominated by the presence of calcium and sulphate ions.
Halophyte	A plant that grows in waters of high salinity, coming into contact with saline water through its roots or by salt spray, such as in saline semi-deserts, mangrove swamps, marshes and sloughs, and seashores.
Key stakeholder	Defined as directly affected parties, those who have a high level of negative or positive influence (in government and civil society domains, and on the direction and success of AMD long-term initiatives) and those whose input is critical to the study (for *e.g.*, representatives of various National, Provincial, and Local Government, NGOs, organised business, mining, industry, labour, agriculture, affected mines, affected water utilities, community leaders, academics, *etc.*).
Layout	The arrangement or configuration (site layout, pipe route, *etc.*) of a specific option.
Long-Term Solution	A solution that is sustainable in the long term with regards to the technical, ecological, legal, economic, financial and institutional aspects.
Option	One of a number of combinations of abstraction works, treatment processes, and solutions for the disposal of waste and utilisation of treated water.
Preferred option	The solution, or combination of solutions, for the three basins respectively and collectively, that will be selected for further investigation in the feasibility phase, and if found feasible, that would eventually be recommended for implementation.
Ramsar Convention	The Convention on Wetlands of International Importance, especially as Waterfowl Habitat - An international treaty for the conservation and sustainable utilization of wetlands, *i.e.*, to stem the progressive encroachment on and loss of wetlands now and in the future, recognizing the fundamental ecological functions of wetlands and their economic, cultural, scientific, and recreational value. It is named after the town of Ramsar in Iran.
Reef	Term used on the Witwatersrand mines for conglomerate containing gold deposits.
Reference Project	The option which uses proven technologies, has minimum risk and which, is used for financial modelling and budgeting. It will probably not be the option which is implemented but is the benchmark against which implementation proposals will be judged.
Reserve	The quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.
Resource Classification	The Classification System provides guidelines and procedures for determining the different classes of water resources. There are three Management Classes, namely “minimally”, “moderately”, and “heavily used”. They describe the desired condition of the water resource and the extent to which it can be utilised.
Resource Quality Objectives	Resource Quality Objectives (RQOs) capture the Management Class of the Classification System and the ecological needs determined in the Reserve into measurable management goals that give direction to resource managers as to how the resource needs to be managed. RQOs may relate to, the Reserve, the instream flow, the water level, the presence and concentration of

	particular substances in the water, the characteristics and quality of the water resource and the instream and riparian habitat, the characteristics and distribution of aquatic biota, the regulation or prohibition of instream or land-based activities which may affect the quantity of water in, or quality of the water resource; and any other characteristic, of the water resource in question.
Resource Water Quality Objectives	Is a numeric or descriptive instream (or in-aquifer) water quality objective, typically set at a finer resolution (spatial or temporal) than Resource Quality Objectives to provide greater detail upon which to base the management of water quality. (Resource Directed Management of Water Quality, 2007).
Request for Information	A Request for Service Providers to provide information (RFI) on their product or service, *e.g.* technologies. It is not part of a procurement process.
Request for Qualifications	A Request for Qualifications (RFQ) from Service Providers to allow a shortlist to be prepared. It is normally the first step in the procurement process.
Request for Proposals	A request for technical and financial proposals (RFP) in compliance with a defined Scope of Work (SoW) and adjudication criteria from (Pre-Qualified) bidders to allow one of the bidders to be appointed to provide an agreed service. Equivalent to Expression of Interest (EOI) but used in infrastructure projects
Scenarios	An alternative projection of the macro environment which affects AMD, such as climate change, electricity load shedding, and changes in quality or quantity of water ingress to the mine void.
Service Provider	The generic term for the Special Purposes Vehicle (SPU) or contracting consortium that will design, build, operate and maintain and possibly finance the works.
Short-Term Interventions (Short-Term Solution as stated in Terms of Reference)	Emergency measures that are being implemented by the TCTA in the short-term in all three the basins while the long-term Feasibility Study is undertaken to protect the ECL, to neutralise the AMD and to remove metals from the AMD.
Socio-Economic Critical Level	The level above which the water at the critical location in the mine void must not be allowed to rise, to protect specific social or economic features, such as the Gold Reef City museum and active or planned mining.
Target Operating Level	The level in the mine void at each abstraction point, at which the water level should generally be maintained by pumping or gravity flow to allow for hydraulic gradient across the underground mining basin, seasonal peak ingress, pump down time, and the like, *i.e.* to provide sufficient buffer capacity or freeboard required below the ECL or SECL across the basin.
Vadose zone	The zone in the soil profile between the surface and the water table.
Water table	The level in an aquifer below which the said aquifer are filled with water.
Western Basin	West Rand underground mining basin.

1 INTRODUCTION

1.1 Introduction to this Report

1.1.1 Report Objectives

This report describes the possible options for the use or discharge of treated water resulting from the treatment process for water from acid mine drainage (AMD). All possible options that have been identified are described.

1.1.2 Structure of Report

The report is structured according to the chapters illustrated in **Figure 1.1** and discussed below.

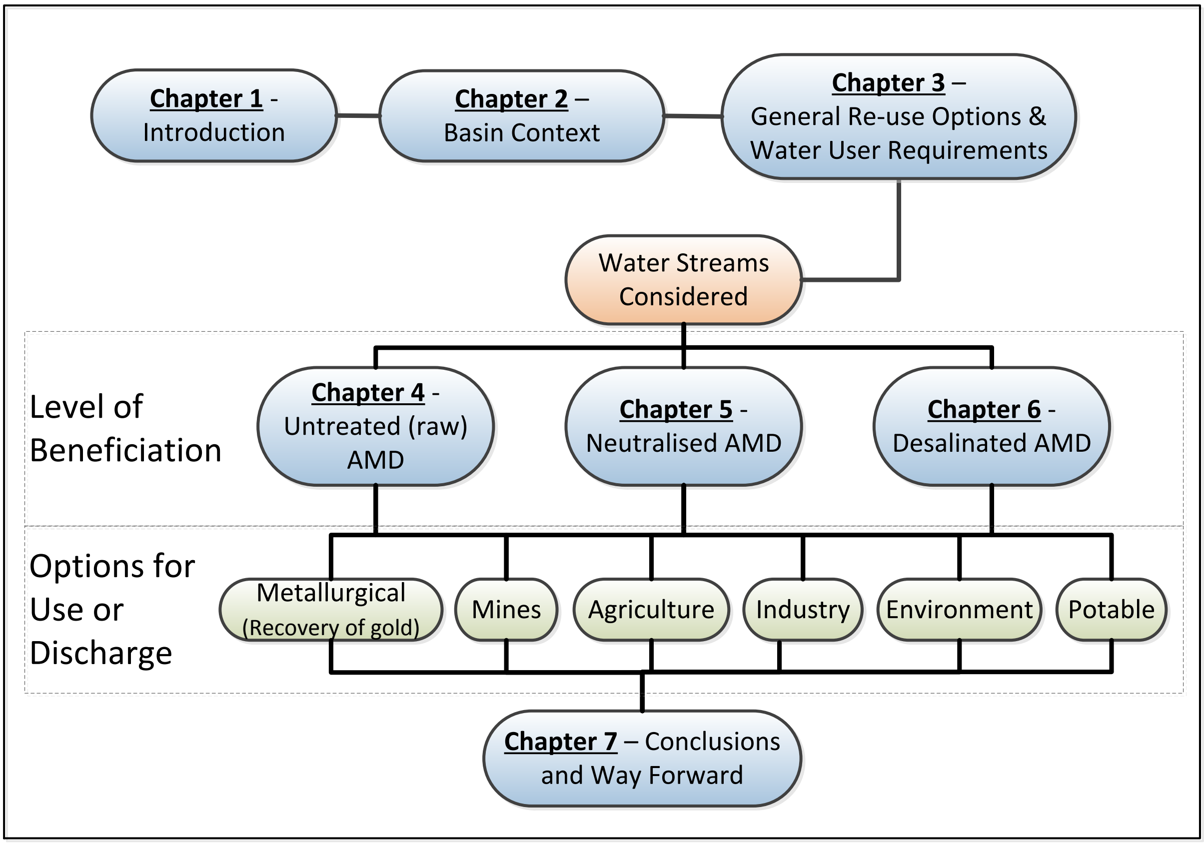

Figure 1.1: Report structure

Chapter 1 provides the structure for this report.

Chapter 2 provides the context of the relevant river systems, such as information on its management strategies and the water quality objectives. A summary of the cost-benefit analysis to be undertaken for different AMD management scenarios are also given in this chapter.

Chapter 3 gives information on general water re-use options and the water requirements for different water use sectors in the area.

Chapter 4 describes options for use, discharge or disposal of **raw AMD**.

Chapter 5 describes options for the use or discharge of the **neutralised water**.

Chapter 6 describes options for the use or discharge of **neutralised and desalinated water**.

Chapter 7 summarises the conclusions and way forward.

2 BASIN CONTEXT

2.1 River System Reconciliation and other Strategies

The options for the use or discharge of water derived from the management of Acid Mine Drainage (AMD) must be evaluated against the backdrop of the river system reconciliation strategies for the Vaal, Olifants and Crocodile (West) River systems.

The local surface water resources for the Vaal and Crocodile (West) Water Management Areas (WMAs) have been fully exploited for more than three decades. It is therefore essential that the strategies be considered if any water becomes available for use (such as raw or treated AMD).

2.1.1 Vaal River System Reconciliation Strategy and Vaal River Integrated Water Quality Management Strategy[1]

a) Objectives

DWA has, as part of the development of the Internal Strategic Perspectives (ISPs) for the Vaal River water management areas (WMAs), identified and prioritised several programmes to support integrated water resource management (IWRM) in the Vaal River System. Amongst these was the need for the establishment and/or updating of reconciliation and integrated water quality management strategies for the Vaal River System.

The objective of the Large Bulk Water Supply Reconciliation Strategies Study for the Vaal River System is to develop strategies to meet the growing water requirements of the industrial and urban sectors that are served by the Integrated Vaal River System.

The objective of the Integrated Water Quality Management (IWQM) Strategy for the Vaal River System is to integrate water quality planning across the various WMAs, taking cognisance of the water quantity requirements and water demand and supply management, to secure water that is fit for use into the future.

The Vaal River Strategies set out to:

- Identify and assess the potential water re-use options in the Upper and Middle Vaal River systems;
- Investigate the feasibility of the re-use options; and
- Make recommendations for further investigation of the most feasible option(s).

b) Area of supply

The Vaal River Reconciliation Strategy deals with a dynamic area with huge growth in water requirements and the need to sustain water supply for social and economic activities. The infrastructure system of the strategy is complex, and furthermore all users contribute to the

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[1] www.dwaf.gov.za/Project/Vaal

effluent and complex water quality issues. Efficient use of this scarce resource is therefore important, and special efforts must be made to ensure that there will be enough water of good quality for this important area.

The area comprises the water resources of the Vaal River System, which includes three of the 19 former WMAs in South Africa, previously the Upper, Middle and Lower Vaal WMAs, stretching from Kuruman in the west to Ermelo in the east and from Johannesburg in the north to the Lesotho border in the south. Other sub-systems also form part of the Integrated Vaal River System.

c) Sources of water

Due to the extensive development in the Vaal River System and Crocodile West WMA, which is partly supplied from the Upper Vaal WMA, the local surface water resources in all three of the Vaal WMAs have been fully exploited for more than three decades.

Some facts about the Vaal Dam catchment and other components of the Integrated Vaal River System are:

- Vaal Dam capacity: 2 570 million m^3;
- Vaal Dam surface area: 32 107 ha;
- Katse Dam capacity: 1 950 million m^3;
- Katse Dam surface area: 3 580 ha;
- Vaal Barrage capacity: 61 million m^3;
- Vaal Barrage surface area: 1 618 ha;
- Sterkfontein Dam capacity: 2 656 million m^3;
- Sterkfontein Dam surface area: 7 000 ha; and
- The Vaal Dam has a catchment of approximately 39 000 km^2, and the Vaal Barrage has a catchment of approximately 11 000 km^2. The combined total catchment area equals approximately 50 000 km^2.

d) Planning for the future

DWA completed the Reconciliation Strategy and an Integrated Water Quality Management Strategy for the Vaal River System in 2009 (DWAF, 2009a; 2009b, 2009c, 2009d), and a Strategy Steering Committee was formed in July of the same year to oversee the implementation of the strategies. The objectives of the strategies are to reconcile the current and future water requirements with the available water by implementing appropriate interventions to increase the available water, conserve water through conservation and demand management measures, and improve the water quality in the river systems.

Over decades, the water resources of the Vaal River System were augmented to match the growing water requirements, and major inter-basin transfer schemes were developed to convey water into the system from the high rainfall regions of the Upper Thukela and Usutu Rivers as well as from the headwaters of the Orange River in the highlands of Lesotho.

The Vaal River System supplies water to about 60% of the South African economy and 45% of the population – the mines and industry on the Mpumalanga Highveld, the bulk of Eskom's coal-fired power stations, Gauteng, the North West and Free State goldfields, Kimberley, iron and manganese mines of the Northern Cape, small towns as well as large irrigation schemes. There are complex issues impacting on the Vaal River System and all users in the area contribute to the effluent and the complex water quality issues.

e) Water Balance and Reconciliation

Figure 2.1 illustrates the main components of the Vaal River Strategy. The yield of the Vaal River System is depicted by the orange line, which will reduce from 2014 onwards due to the releases that will be required to dilute the Vaal River water to an acceptable quality unless the AMD-related salinity is addressed. Even with the earliest introduction of the second phase of the Lesotho Highlands Water Project, the Polihali Dam in 2020, there will still be deficits (red area) that could have enormous financial implications. This is further discussed in DWA AMD FS 2013, Study Report No. 7: "**Institutional, Procurement and Financing Options"**. The estimated yield of Polihali Dam is shown above the reduced system yield in **Figure 2.1**.

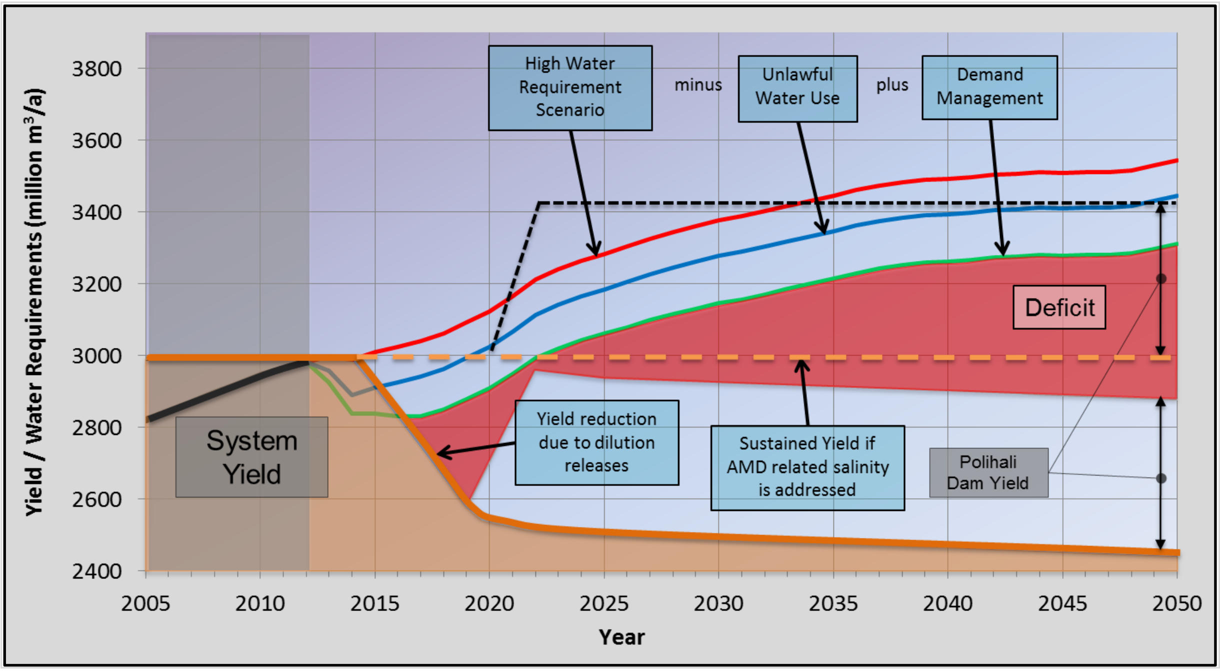

Figure 2.1: Vaal River system demand and supply scenarios

The strategies to be implemented are as follows and shown in **Figure 2.1**:

- Eradicate unlawful water use, which will reduce the water requirement (from the red line to the blue line. The strategy takes into account that there may be some of the original perceived unlawful use that will turn out to be lawful. To allow for this it is assumed that only 85% of the original perceived unlawful use will be eradicated;

- Implement water conservation and water demand management to reduce water use by 15% (from the blue line to the green line);
- Implement Phase 2 of the Lesotho Highlands Water Project (Polihali Dam and conveyance infrastructure); and
- Address the AMD-related salinity to sustain the current system yield into the future.

Successful implementation of all these strategies is necessary to maintain a positive water balance until 2050 and beyond. The Polihali Dam yield is also shown, by the dashed black line, above the scenario where AMD-related salinity is managed. The uncertainties in achieving a scenario where no deficits occur are immense, and failure to implement any of the strategies successfully could result in deficits.

It must be emphasised while the quantity of AMD from all three basins is not very significant as a resource in the Vaal River System, it is still important and should be used. However, the volume of the dilution releases required to curb the effect of the AMD related salt loading is very significant and will threaten the supply security. It is estimated that these dilution releases can lead to a reduction in the yield of the Vaal River System of up to 500 million m^3/a.

f) Implementation: Strategy Steering Committee

A Strategy Steering Committee was established to take the Reconciliation Strategy and Integrated Water Quality Management Strategy forward as the next step in the management of the Vaal River System.

The membership of the Strategy Steering Committee is similar to that of the Project Steering Committees during the previous phases when the strategies for the Vaal River System was developed. The Strategy Steering Committee comprises representatives of agriculture, local authorities, water service providers, mines, the energy and industry sectors, national and provincial government departments and civil society representing a wide variety of stakeholder groups in the Vaal River System.

The objectives of the Strategy Steering Committee are to:

- Ensure the implementation of the recommendations of the Vaal River System Reconciliation Strategy;
- Ensure the implementation and recommendations of the Vaal River System Integrated Water Quality Management Strategy;
- Update both strategies to ensure that they remain relevant; and
- Ensure that the strategies and their recommendations are appropriately communicated.

2.1.2 Olifants River System Reconciliation Strategy[2]

a) Area of Supply

The Olifants River Water Supply System provides water for domestic and industrial water use purposes, irrigation, mining and power generation. The system serves more than 3 million people, providing domestic water to towns and rural areas in the Olifants catchment as well as to the towns of Polokwane and Mokopane and their surrounding rural areas to the north and outside of the catchment area.

b) Planning for the Olifants River Water Supply System

The Reconciliation Strategy for the Olifants River Water Supply System was completed towards the end of 2011 (DWA, 2012). The aim of the strategy was to reconcile future water requirements with supply for a 25-year planning horizon, and to provide a framework for decision-making.

c) Strategy Steering Committee

A Strategy Steering Committee for the Olifants River Water Reconciliation Strategy was established. This committee has representatives, among others, from national departments involved in water resource management, including the regional and national offices of DWA, relevant provincial departments, organised agriculture, relevant district and local municipalities, the mining sector and Eskom. The Strategy Steering Committee actively monitors the implementation of the strategy by all role players.

d) Water requirements and availability

Figure 1.3 shows the current system yield and the expected high and low water requirements until 2035. The system yield includes transfers of water into the Olifants River catchment from the Vaal, Usutu and Komati River catchments totalling 228 million m^3/a for the seven Eskom power stations within the catchment. The system yield will increase as a result of the commissioning of the De Hoop Dam in 2012/13. The ecological Reserve for the Olifants River catchment has not yet been operationalised, and it has been assumed that this will be implemented when the De Hoop Dam reaches full capacity. It has been established that the ecological Reserve will reduce the available yield by approximately 157 million m^3/a.

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[2] www.dwaf.gov.za/Projects/OlifantsRecon

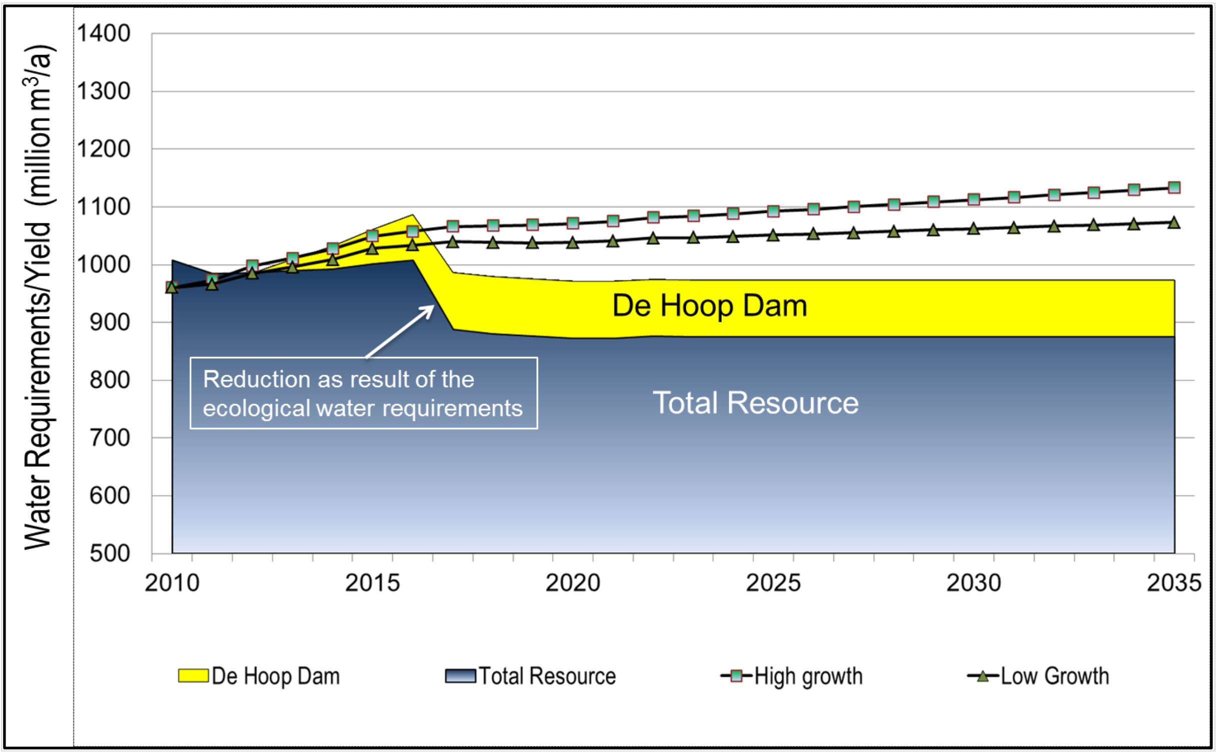

Figure 2.2: Olifants River System demand and supply scenarios

The graph in **Figure 2.2** shows that without implementing interventions that will either reduce the water requirements or increase the water supply, the system will encounter water deficits just after the implementation of the ecological Reserve in 2017.

e) Water Quality

There are some serious water quality problems in the Olifants River catchment. Localised water quality problems must be addressed through intensified compliance monitoring and enforcement and by reducing pollution at source. A separate water quality management strategy is envisaged to address the water quality issues.

The water quality in the study area does not affect the availability of the resource (*i.e.* dilution is not yet required). At many monitoring stations, however, there is an upward trend in pollution, which requires immediate attention to ensure the sustainability of the resource.

f) Supply interventions to meet future needs

The following interventions are needed to overcome the expected water deficit from 2017:

- Interventions that will reduce the water requirements:
  - Water conservation and demand management for the irrigation, urban and mining water use sectors, to be phased in over five years for the former two sectors and over ten years for the latter, all from 2013; and
  - Eliminating unlawful water use, to be phased in over five years from 2015.
- Interventions that will increase the water supply:

- Removal of invasive alien plants, to be implemented over 25 years from 2010 (as a continuation of the programmes already running);
- Groundwater development over 23 years from 2012;
- Treatment of additional decant water from existing coal mines, as well as decommissioned and rehabilitated coal mines; and
- Sewage water re-use in Polokwane and Mokopane. This takes account of the existing situation in which the Mogalakwena Platinum mine receives sewage effluent from both the Polokwane and Mokopane WWTW.

g) Successful implementation of interventions

DWA, as trustee of the country's water resources, is only facilitating the process of water reconciliation planning, and the implementation of the interventions is the responsibility of many more institutions. Without a concerted effort by all role players, water reconciliation cannot be achieved over the forthcoming years. It is therefore imperative that all relevant institutions work closely together.

2.1.3 Crocodile River West System Reconciliation Strategy[3]

a) Area of supply

The Crocodile River West catchment extends northwards from the catchment divide in central Johannesburg to the Limpopo River. It is characterised by the sprawling urban and industrial areas of northern Johannesburg and Pretoria, extensive irrigation downstream of the Hartbeespoort Dam, and large mining developments north of the Magaliesberg.

The Crocodile River West has thus been very heavily influenced by human activity. Noting significant overlap with the Vaal River System, the Crocodile River West water supply system serves a population of about 5.5 million, with over 20% of the national Growth Domestic Product (GDP) generated in the Crocodile River West catchment.

b) Sources of water

The water resources that occur naturally in the Crocodile River West catchment have been fully developed and utilised. Supplies to northern Johannesburg, Midrand, Pretoria and environs are transferred in from the Vaal River via the Rand Water distribution network. This represents over 45% of the total water use in the Crocodile West catchment, and results in large volumes of return flow (primarily effluent discharges) of what was originally Vaal River water being discharged into the Crocodile River West and its tributaries. This, in turn, constitutes an important source of water for downstream users.

c) Planning for the future

A water resources study entitled *Development of a Reconciliation Strategy for the Crocodile (West) Water Supply System* was completed in 2009 (DWA, 2009b). The broad strategy for

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[3] www.dwaf.gov.za/Projects/crocodilemaintenance

the management of water resources with respect to the Crocodile River West System is summarised below:

- Water for urban and industrial use in the area south of the Magaliesberg should continue to be supplied predominantly from the Vaal River System via Rand Water. Water for irrigation and rural users should be supplied from local sources;
- The bulk of the water available in the area north of the Magaliesberg consists of a combination of local surface resources and return flows. The growth in water requirements in this area will be supplied from the growth in return flows from northern Gauteng, while some rural users should continue to be supplied from groundwater; and
- Large quantities of water need to be transferred to the rapidly developing Lephalale area to augment the local resources. Water for these transfers can mostly be sourced from the Crocodile River by using the surpluses available from return flows in the catchment. Further augmentation from the Vaal River System has been considered but is not currently being planned.

d) Water balance and reconciliation

The light blue shaded portion of **Figure 2.3** represents the water balance for the whole Crocodile River West catchment for a scenario with high population growth and medium water demand management. This is the balance (surplus) after supplying water to all users in the catchment.

The growing water requirements in the Lephalale area in the Mokolo River catchment to the north and north-east of the Crocodile River catchment exceed the available water from the Mokolo River system. Projects are currently being undertaken by the Department of Water Affairs to transfer surplus water in the Crocodile River System to the Lephalale area (Mokolo-Crocodile Water Augmentation Project).

There are currently two sets of water requirements for that area, namely, the 2012 Lephalale base demand scenario and the 2012 Lephalale high demand scenario. The light green and orange lines in **Figure 2.3** show the net water requirements for these two scenarios after taking the available yield from the Mokolo River system into account. It can also be seen that the surplus water in the Crocodile River catchment, if it were considered for transfer to the Lephalale area to meet the expected shortfall there, would be insufficient to supply the total water requirements.

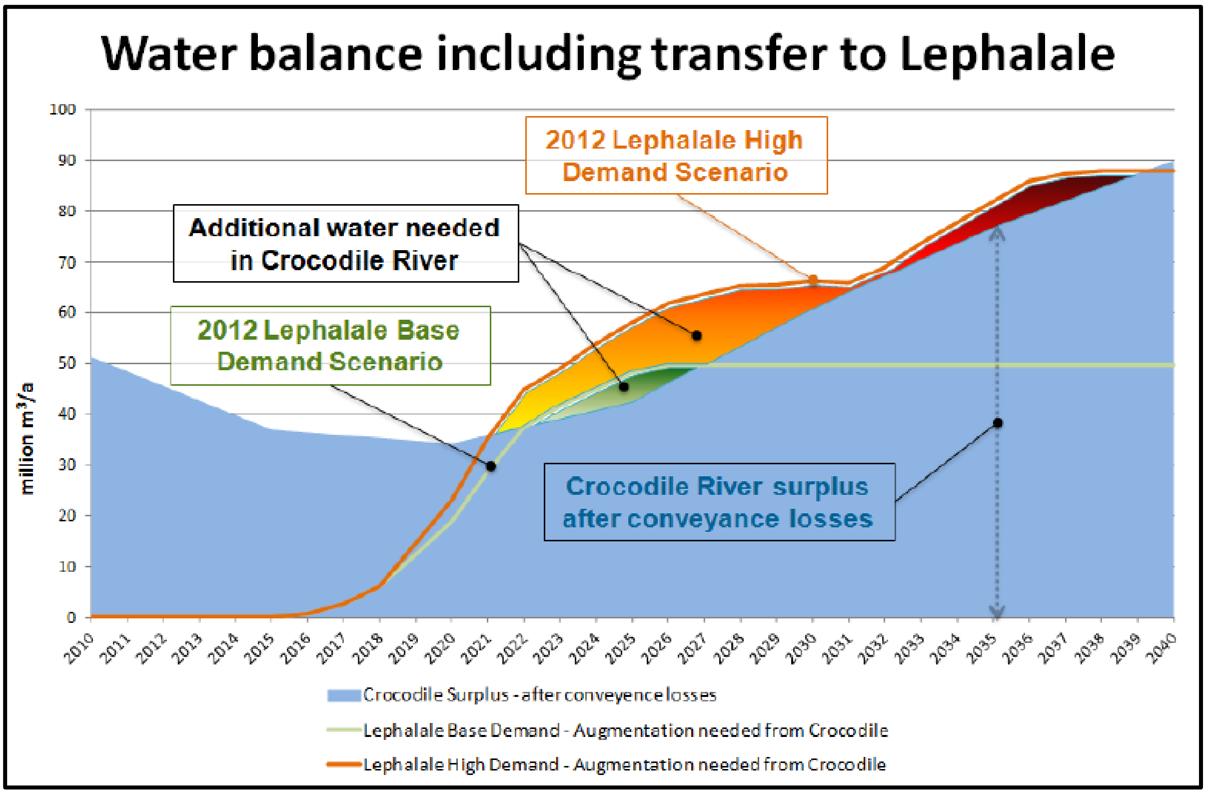

Figure 2.3: Crocodile River West System demand and supply scenarios

The green and orange/red areas in the upper part of **Figure 2.3** indicate expected shortages in the Lephalale area after transferring surplus water in the Crocodile River System to Lephalale. These expected shortages are amplified in **Figure 2.4**.

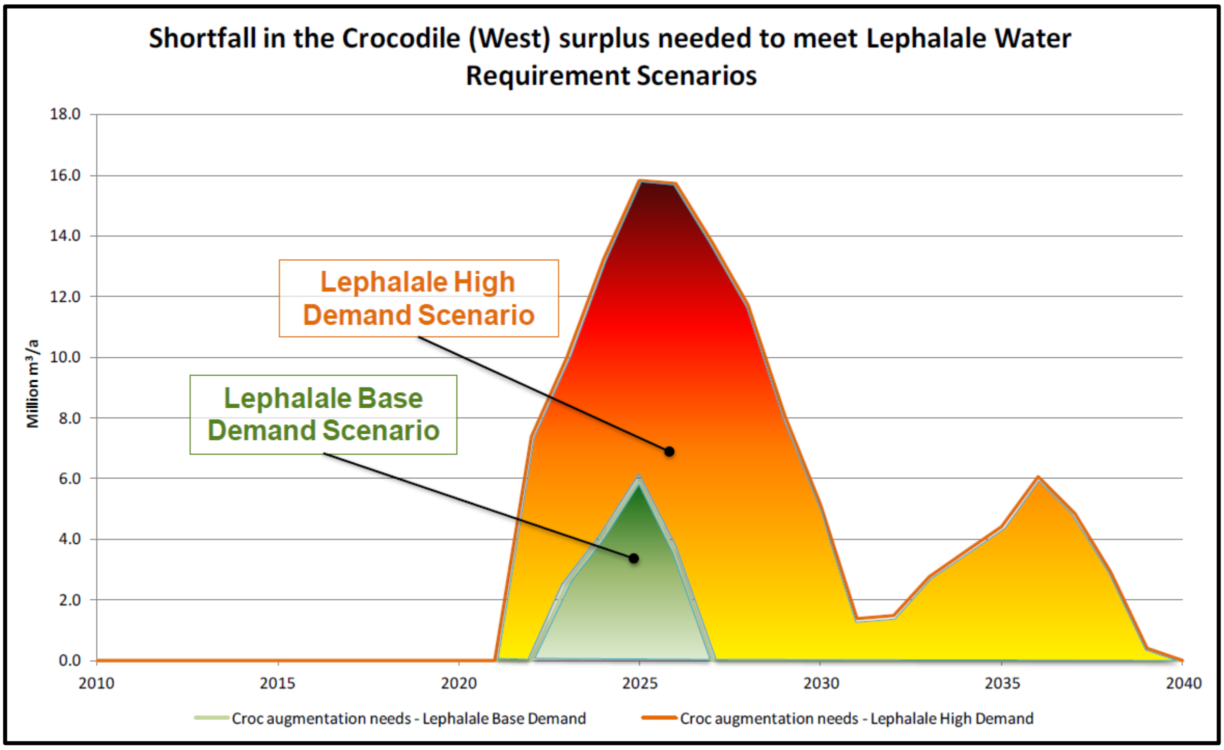

Figure 2.4: Crocodile River System: expected shortfall to supply Lephalale

In the Lephalale base demand scenario, shortfalls of up to about 6 million m^3/a could occur between 2022 and 2025. In the Lephalale high demand scenario, shortfalls of up to about 16 million m^3/a could occur between 2021 and 2040. The shortfall is relatively small and temporary. Either infrastructure or demand interventions could be considered to achieve a positive water balance.

A Strategy Steering Committee comprising key role players and decision-makers was constituted in July 2010. This committee monitors the growth in return flows, and has regular discussions with developers in the Lephalale area (Eskom, Sasol and others) regarding their requirements. The water resource and water quality models are regularly updated and refined to enable detailed and timeous adjustments to the strategy and decisions on further augmentation needs.

2.2 Cost Benefit Analysis of AMD-Related Salinity Management Scenarios

2.2.1 Introduction

One of the Feasibility Study's deliverables is an Economic Assessment of the long-term solution that will be proposed to investigate the economics of the project. The economic analysis will assess the cost benefit and the macro-economic impact of implementing the LTS for the AMD. The details and results of that analysis will be included in DWA AMD FS 2013, Study Report No. 7: **"Institutional, Procurement and Financing Options"**.

2.2.2 Cost Benefit analysis of implementing the proposed LTS

As described in **Chapter 2.1.1** the DWA strategy for managing the Vaal River System (DWAF, 2009a, 2009b) includes the decision that the salt load from AMD which will flow into the river system should be removed or prevented from entering the main river system. One of the inputs to that decision was a cost-benefit analysis of the alternative scenarios that were considered for managing the salinity of the AMD in the Vaal River System. That analysis was based on the understanding of the cost and benefits at that time.

In this section a description of three alternative scenarios for cost-benefit analysis to be performed are presented. In all three scenarios the proposed STI to neutralise the AMD, with some reduction in salinity, is assumed to be implemented. The three scenarios are described in the following sections:

a) Scenario 1: Do Nothing

For this scenario no dilution releases will be made from the Vaal Dam and there will be no reduction of AMD-salinity in the Vaal River System. This will lead to higher salinity levels downstream of the Vaal Barrage of which the economic impacts have to be assessed. It will also impact on the tributaries from the point where the water is released until it reaches the Vaal Barrage. The cost benefit analysis for this scenario will be conducted for the impact of a range of Total Dissolved Solids (TDS) levels that will occur in the Middle and Lower Vaal WMAs. A range of TDS levels will be considered to compare the effect that varying raw AMD qualities will have on the analysis.

This scenario will undoubtedly have severe environmental impacts for an area far greater than just the Witwatersrand region and will also externalise the economic impacts to downstream users located outside of the study area. Even though it is widely acknowledged that the "Do Nothing" scenario is not acceptable, it will be necessary to perform a cost benefit analysis to provide a base case against which other scenarios can be compared.

b) Scenario 2A: Dilution without early implementation of the Thukela Water Project

Under this scenario once neutralised AMD is released into the river system continuous dilution releases from Vaal Dam will be made in order to maintain the Interim Resource Water Quality Objective (RWQO) of 600 mg/ℓ for TDS in the Vaal Barrage and downstream. The Thukela Water Project (TWP) will not be commissioned until required for normal augmentation (as if dilution releases had not been made) and this will be after 2050.

The dilution releases will result in deficits from 2016 until the full annual volume of water is transferred from the LHWP Phase II (Polihali Dam) in about 2022. At that time the deficit fill will be very small but will increase, due to the increasing demands on the system, until the end of planning horizon (2050) and beyond. The cost benefit analysis for this scenario will assess the impact of water restrictions on the users of the Vaal River System as well as the impact of neutralised but saline water on receiving streams.

This scenario is expected to have severe economic impacts due to the probable water restrictions and also degrade receiving streams because of the high salt loading. The calculations for this scenario will be based on maintaining the interim RWQO of 600 mg/ℓ for TDS in the Vaal Barrage and downstream. However, the recommended RWQO is 450 mg/ℓ for TDS, which will require more dilution releases if implemented and thus increase the cost associated with this scenario.

c) Scenario 2B: Dilution with Thukela Water Project Implemented

This scenario will be analysed with the TWP commissioned in 2025 to augment the Vaal River System and continuous dilution releases made from Vaal Dam in order to maintain the interim RWQO of 600 mg/ℓ for TDS in the Vaal Barrage.

Deficits will occur from 2016 until the full annual volume of water is transferred from the LHWP Phase II (Polihali Dam) in about 2022. The deficit will increase with increasing demand until 2025 when the TWP is commissioned. In the cost benefit analysis for this scenario the costs of the TWP will be included from 2015 to allow for commissioning in 2025, the impact of probable water restrictions will be assessed and the impact of neutralised, but saline water on receiving streams will be considered.

This scenario is expected to have severe economic repercussions due to the increased expenditure, the probable water restrictions and also the degradation of the receiving streams because of the high salt loading. The calculations for this scenario will be based on maintaining the interim RWQO of 600 mg/ℓ for TDS in the Vaal Barrage and downstream. However, the recommended RWQO is 450 mg/ℓ for TDS, which will require more dilution releases if implemented and thus increase the cost associated with this scenario.

d) Scenario 3: Long-term Solution for AMD

For this scenario, the AMD generated in the Central and Eastern basins will be neutralised and the salts released into the Vaal River System will be reduced. The salinity of the water released into the Vaal River System will be no greater than that of potable water (Rand Water quality). The AMD salt loading would also be reduced in the Western Basin but the AMD discharges into the Crocodile River West System so the costs for the Western Basin will not be included, since the cost benefit analysis will only be done for the Vaal River System.

Until the long-term solution is in place (*i.e.* salinity is addressed), dilution releases from Vaal Dam will be made in order to maintain the interim RWQO of 600mg/ℓ for TDS in the Vaal Barrage. To meet the growing demands, the LHWP Phase II (Polihali Dam) will have to be commissioned in 2022, while the Thukela Water Project can be delayed until after the end of the planning horizon (2050).

The cost benefit analysis will assess the impact of discharging neutralised, but saline water to receiving streams in the short-term until the LTS is commissioned and the costs of the LTS for the Central and Eastern Basins.

In this report, options for how the AMD can be applied for different uses in order to achieve the appropriate level of neutralisation and salinity reduction in the river systems are discussed. Possible uses for AMD that is treated to different standards (*e.g.* raw AMD, neutralised AMD, neutralised and desalinated AMD) is considered and recommendations are made to provide a solution that will meet the required standards with acceptable associated risks.

2.3 Water Quality Context of Receiving River Systems

2.3.1 Environmental Water Quality (Receiving Water Quality Requirements)

a) Hierarchical Approach to Discharging Water, or Water containing Waste

Discharging AMD, whether raw or treated, into either of the two potential catchments (Vaal or Crocodile (West) Rivers) would be subject to DWA’s hierarchical decision-making approach.

Pollution prevention forms the foundation of the decision-making hierarchy used by DWA with the purpose of protecting the water resource from waste impacts. This hierarchy is based on a precautionary approach, and the following order of priority for wastewater management decisions and/or actions is applicable: firstly, pollution prevention is at the crux of the management principles, followed by the minimisation of impacts on the receiving environment, and finally only allowing the discharge of water containing waste based on a site-specific risk approach, including the risk to water users receiving water of that quality. The water quality requirements of all users (including in-stream water users) are applied in order to evaluate the potential water quality impacts of discharging raw or treated AMD to the river systems.

b) Resource Quality and Resource Directed Measures

Water resources in South Africa are managed to meet the water quality requirements of all recognised water users. Water quality is inextricably linked with water quantity (typically water flow), in-stream and riparian habitat and aquatic biota integrity, all of which are collectively referred to in the National Water Act, 1998 (Act No. 36 of 1998) (NWA 36:1998) as the “resource quality”.

For water resources to be able to continuously sustain economic growth and social development, the quality (or “resource quality”) of such water resources needs to be maintained within certain pre-determined parameters. These resource parameters, or Resource Directed Measures (RDMs), are represented by the Resource Management Class, Resource Quality Objectives (RQOs) and the Reserve.

c) Resource Water Quality Objectives

Resource Water Quality Objectives (RWQOs) constitute planning objectives that specifically apply to the water component of resource quality. The determination of RWQOs is influenced by the socio-economic need to utilise the capacity of water resources to assimilate waste, on the one hand, and on the other hand, by the need to protect the said water resources in order to ensure healthy functioning aquatic ecosystems together with water that is fit for use by the recognised water user sectors. In short, RWQOs are a mechanism through which the balance between sustainable and optimal water use and protection of the water resource can be achieved.

RWQOs are a pre-requisite when planning for water quality. The determination of RWQOs provides the basis for conducting water quality reconciliation, water quality allocations, benchmarking during water quality foresight, and the determination of water quality stress. In addition, RWQO’s also allow for meaningful water quality scenario analysis, intervention planning and strategy establishment; the aforementioned all being central to Water Quality Planning (WQP).

RWQOs are aimed at ensuring that local priorities are appropriately balanced with broader spatial and temporal perspectives at water management area (WMA) and national levels and at meeting the objectives of the Resource Directed Measures (RDM) and those in the National Water Resource Strategy. They incorporate stakeholder needs, give effect to the RDM and stipulate the tolerable level of impact collectively produced by upstream users.

RWQOs form part of the mechanism for making the definition of pollution in terms of the NWA (36:1998) operational in the current context of resource-directed water quality management (DWAF, 2006e), which allows for different levels of impact for different water resources.The NWA (36:1998) allows for the determination of preliminary RQOs for water resources before the formal classification system is established. Once RQO have been published in the Gazette, or preliminary RQO determined, they must be given effect (NWA 36:1998, Section 15).

To do so, the Department or Water Management Institutions (like Catchment Management Agencies) may also set narrative or quantitative RWQOs. These may be set at a higher spatial resolution (*i.e.* closer together) and/or temporal resolution (*i.e.* more frequently monitored) than the RQO (preliminary or otherwise) to which they may be linked. The purpose of these will be to provide greater detail upon which to base management of water quality aimed at achieving and sustaining compliance with RQOs to ultimately allow realisation of the catchment vision. The catchment vision is a collective statement from all stakeholders of their future aspirations with respect to the relationship between themselves (in particular their quality of life) and the water resources in the catchment. The RWQOs form part of the strategy to attain that vision. RWQOs will not be gazetted as such, but will provide the water quality input to the formal RQO process. It would, therefore, be possible to have more RWQOs than RQOs if so desired.

In the light of the discussions above, it can be determined that the RWQOs are a key aspect when considering possible discharge options for raw or treated AMD. If any such option is considered, it needs to be determined whether there is adequate assimilative capacity in the river system to accommodate AMD of a certain quality and quantity without violating the RWQOs, and also without threatening the water supply security of the river system.

RWQOs are to be used as a preliminary receiving requirement and a departure point to guide acceptable discharge concentrations into the receiving water environment at the selected discharge locations, as identified in the TCTA Due Diligence Report (TCTA, 2011). To determine whether discharge of raw or treated AMD will be acceptable, it will be necessary to conduct water quality modelling to confirm if the RWQOs will be violated or not if such discharge took place.

The proposed RWQOs for the Klip River and Suikerbosrant catchments were accepted during the Vaal River Reconciliation Strategy Study (DWAF, 2009a; 2009b) and the Integrated Water Quality Management (IWQM) Strategy Study (DWA, 2009c, 2009d). RWQOs for the major tributaries of the Vaal River (level 2 points, the Vaal River main stem being level 1) are available, and hence the RWQOs for the sub-catchments of the Upper Vaal WMA. These RWQOs have been set through a consultative process with various well-established catchment forums over recent years involving the relevant DWA Regional Office and water users in the Upper Vaal catchment. Water users have taken ownership of these RWQOs, and they are used in the management of water quality in the respective sub-catchments.

d) Summary of Water Quality Issues

Recent studies have focused on the understanding of catchment status and water users, and on the establishment of RWQOs within the various sub-catchments. Various initiatives are under way at different stages of development in the sub-catchments of the Vaal River System, but many of these are being done in isolation without consideration of the Vaal River main stem. Salinity and eutrophication have been identified as the two primary water quality issues affecting the Vaal River System in its entirety, and are affecting all related WMAs due to their interdependency.

Much of the Vaal River System can be considered to be under water quality stress, as it is unable to adequately meet the needs of users in respect of their water quality requirements. There is an imbalance between sustainable and optimal water use, and protection of the water resource. Options exist to supplement water in the Vaal River System with water from the Lesotho Highlands Water Project, which would provide additional assimilative capacity to accommodate current salt loads, but this would not be a sustainable solution. The Vaal Barrage has an interim RWQO of 600 mg/ℓ for TDS, which is used for operating releases from the Vaal Dam, but the eventual RWQO is recommended to be set at 450 mg/ℓ.

DWA has developed a Water Resource Classification System, which includes the determination of RQOs (resource quality objectives include all aspects of the resource: quantity, water quality, in-stream habitat and biota). The process involved the associated required public participation. A comprehensive Reserve determination for the Vaal River has been done, but the Reserve is yet to be finalised according to the outcome of the classification which has been formally gazetted, although it is not envisaged that the outcomes in the Reserve document will change.

Table 2.1 and **Table 2.2** summarise current water quality issues in the Upper Vaal River and Upper Crocodile River West catchment.

Table 2.1: Summary of water quality issues in the Upper Vaal River and Upper Crocodile West catchment

Catchment	Sub-catchment	Salinity	Nutrients	Other
Upper Vaal River	Products of the mining industry in the Upper Vaal WMA include precious metals (*e.g.* gold, uranium.), base metals, semi-precious stones, industrial minerals and coal. The impact of mining on the economy of this area is substantial. The Vaal Barrage sub-catchment (which includes the Suikerbosrant and Klip River quaternary catchments) is one of the most complex catchments in South Africa. It is highly developed with industries, urban areas and mining activities. Over 90% of the dry weather flow is made up of return flow emanating from the respective tributaries. **Suikerbosrant and Blesbokspruit Rivers** About 50 million m^3/a (137 Mℓ/d) of treated urban wastewater is discharged into this river system as well as mine water discharges from Grootvlei Mine (now referred to as Petrex Mine). Furthermore, run-off from the paved urbanised areas in the Suikerbosrant catchment also contributes to the flow in the river. There is no storage structure that can regulate the flow in this river reach (DWA, 2011b). The Blesbokspruit wetland is situated in Gauteng province (26° 17’ S; 28° 30’ E). It covers approximately 1 858 ha (18.6 km^2). The site is approximately 3 km east of the town of Springs on the East Rand of Gauteng province. The towns of Boksburg,	The current state of the system shows salt concentrations which is indicative of an unsustainable system. This increase in TDS concentration upstream from Vaal Dam is attenuated by the Vaal Dam. Downstream from the Vaal Dam the problem of TDS increases almost three fold, where the impact of the Vaal Barrage is seen. The increase in the TDS concentrations is attributable to the highly impacted tributaries that drain into the Vaal Barrage but also includes some contribution of diffuse pollution. These main tributaries include the Rietspruit, Klip, Suikerbosrant, Leeuspruit and Taaibosspruit rivers.	The current state of the system shows unacceptably high nutrient loads.	

Catchment	Sub-catchment	Salinity	Nutrients	Other
	Benoni and Brakpan lie to the northwest, and Nigel is located south of the site. The Blesbokspruit Ramsar Wetland is seasonally important for several species of locally migrant water birds and various notable mammals. The site was placed on the Montreux Record[4] in May 1996 in response to contamination by large quantities of polluted water discharged from adjacent mines upstream of the Ramsar site. The primary cause of the degradation of the Ramsar site is the old Grootvlei Mine now known as Petrex Mine, which continues to discharge polluted water into the wetland. The impacts are manifested in the following ways: firstly, water quality has deteriorated, resulting in a decline in the abundance and diversity of aquatic animal species, as well as loss of species at certain trophic levels; and secondly, the seasonal fluctuation in water levels in the wetland has been replaced by permanently flooded conditions. **Klip River quaternary catchment** This river reach receives about 200 million m^3/a (548 Mℓ/d) of treated urban wastewater which has significantly changed the flow pattern from natural conditions. There is also significant run-off from the paved urbanised areas contributing to the flow in the Klip River, and discharges received from the mines are estimated at approximately 10 million m^3/a (27 Mℓ/d).			

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[4] The Montreux Record is “a record of Ramsar sites where changes in ecological character have occurred, are occurring or are likely to occur”.

Catchment	Sub-catchment	Salinity	Nutrients	Other
	There is no storage structure that can regulate the flow in this river reach. Water quality problems are related to upstream activities, especially from industry, mining and urban activities (DWA, 2011b). The Klip River wetland area, located to the south of Johannesburg, plays a vital role in this densely populated metropolitan region, as it acts as a purifier of polluted water that enters the river from the urban, mining and industrial complex. However, the capability of this wetland to serve this crucial role has been compromised and faces a number of challenges. One of the major challenges is the reduction of water flowing through the wetland as a result of irrigation canals that have cut back and avulsion has occurred, forming a continuous channel. The wetland's capability to remove contaminants from the water is therefore compromised. Previous investigations have determined that the Klip River wetland is in an advanced state of collapse.			
Crocodile (West) River	**Upper Crocodile, Quaternary Catchment A21** The southern part of the catchment is highly developed through the large industrial, urban and semi-urban sprawls of northern-Johannesburg, Midrand and southern Pretoria. Large volumes of water are imported from the Vaal River system via Rand Water, because local sources cannot meet current	Increases in salinity and nutrient concentrations in the water also result from irrigation return flows, and severe eutrophication problems are experienced at Hartbeespoort Dam as well as Roodeplaat, Rietvlei, Bospoort and Vaalkop Dams (DWAF, 2004a).	Informal settlements without access to sanitation, sewage spills from poorly maintained or overloaded sewage networks (Sandton and Alexandria), industrial and agricultural pollutants have all contributed to a build-up	The contribution of mine dewatering to the surface and groundwater resources in the Roodekoppies Dam catchment (Quaternary Catchments A21J–L) is assumed to have some negative impact on users and the environment (DWAF, 2004a).

Catchment	Sub-catchment	Salinity	Nutrients	Other
	water requirements. Large return flows of treated wastewater are generated, which supply other downstream users. A concern is the high projected growth in water demand required to sustain economic growth in the region (DWAF, 2004a). These demands have to be met through additional transfer schemes and would result in higher return-flow volumes. The overall eco-status of this sub-catchment is poor, and the drivers of change are urbanisation (increased impervious surfaces, lack of sufficient capacity of sewer systems, and substantial channel and flow modification) and increased change in land use from natural to urban and industrial (DWAF, 2005a).		in the nutrients in the rivers of the Hartbeespoort (Quaternary Catchments A21B-H) catchment (DWAF, 2004a).	

Table 2.2: Aquatic ecosystem health issues in the Upper Vaal River and Upper Crocodile West catchment *(Department of Water Affairs and Forestry, 2005)*

Sub-catchment	Overall Eco-status	Ecosystem water quality
Upper Crocodile (Quaternary Catchment A21)	The in-stream habitat integrity is poor because of urban development: – most of the river is canalised, urban run-off is high because of paved areas and sewage spills, and industrial discharges are common because the infrastructure cannot cope with the high levels of utilisation. It should be mentioned that some of the tributaries feeding the Crocodile River are not as severely impacted. The riparian zone habitat integrity is also poor, primarily because the river has been engineered and the flow patterns completely altered. The riparian vegetation integrity is poor: the natural vegetation has been completely altered because of urbanisation, and encroachment by poplar species is severe (DWAF, 2005a). The ecological importance and sensitivity (EI&S) is marginal/low; and the number of functional habitat types and species diversity is low because of the complete alteration of channel morphology and the natural flow regime. The African bullfrog is a unique species that manages to survive in this reach of river, but is under constant threat as a result of changing land use.	Water quality is poor with high levels of nutrients and an increased frequency of water quality problems. The percentage of species tolerant to organic pollution indicates that the water is free from significant organic pollution. Water quality in the urban areas is poor, mostly because of sewage spillages and industries discharging into the sewer network. The sewerage system is not able to cope with the increase in housing density.
Upper Vaal	The present ecological state (PES) of the Suikerbosrant River is Category C (fair), which represents a moderately modified state of ecological integrity. The Reserve determination has been done on a comprehensive level. The PES of the Blesbokspruit is Category E (unacceptable), with limited opportunities to improve to Category D unless significant improvement in water quality is achieved. Both the ecological importance (EI) and ecological importance and sensitivity (EI&S) of this river are low (DWA, 2011b). The PES of the Klip River is Category E, with limited opportunities to improve to Category D unless a significant improvement in water quality is achieved.	Water quality issues relevant to the Blesbokspruit include elevated nutrients levels and sediment loads due to agricultural activities, instream dams for agricultural water supply which lead to temperature fluctuations, and some mining activities resulting in elevated salt loads. This catchment is highly modified, and the present water quality reflects the impacts of the developments. Water quality problems in the Klip River are related to upstream activities, especially from industry, mining and urban activities. However, if some of the sewage flows are removed and do not discharge into the river, then some improvement in fish life might be possible (DWA, 2011b). The Reserve determination was done on an intermediary level.

2.3.2 Resource Water Quality Objectives for the Specific Catchments

Based on the defined criteria and the identified considerations, as well as the key drivers per river reach, RWQOs were set for the selected water quality variables (DWAF, 2009d).

a) Blesbokspruit as a Tributary of the Suikerbosrant River

The Suikerbosrant River after the confluence with the Blesbokspruit is heavily used and impacted. Water quality requirements in the Suikerbosrant River catchment, just before the confluence with the Blesbokspruit, are indicated in **Table 2.3** below, taking the receiving water users into consideration.

Table 2.3: First-order assessment of the existing resource water quality objectives for the Suikerbosrant River

Variable	**Units**	**5th percentile**	**25th percentile**	**50th percentile**	**75th percentile**	**95th percentile**	**RWQOs set by the DWA Regional Office and forums as the acceptable level for all users**	**Proposed changes to the RWQOs suggested in the Vaal River IWQMS Study**
Nitrate	mg/ℓ as NO_3	0.02	0.05	0.03	0.54	2.29	0.5 – 3.0	0.05 – 0.25
Ammonia	mg/ℓ as N	0.02	0.02	0.041	0.08	0.3	0.1 – 1.5	0.03 – 0.15
Sulphate	mg/ℓ						150 – 300	None
Chloride	mg/ℓ	35.445	82.175	119.2	161.4	213.425	80 – 150	None
EC	mS/m	46.95	90	110.7	160	250	45 – 70	None
TDS	mg/ℓ	305.175	585	719.55	1 040	1 625	292.5 – 455	None
Phosphate	mg/ℓ as P	0.006	🟦	🟦	🟦	0.71675	0.2 – 0.4	0.03 – 0.15
Aluminium	mg/ℓ						< 0.3	0.05 – 0.10
TP	mg/ℓ							0.05 – 0.25
TN	mg/ℓ							0.25 – 0.50
Faecal coliforms	#/100 mℓ							130 – 500
Algae	µg/ℓ Chl-a							10 – 20

Source: DWAF (2009d)

Key to colour codes

Ideal	**Acceptable**	**Tolerable**	**Unacceptable**

RWQOs were determined for the Suikerbosrant quaternary catchments, including the Blesbokspruit, during the Development of an Integrated Water Quality Management Strategy for the Vaal River System (DWAF, 2009d). The development of level 1 and level 2 RWQOs during this study was done at a desktop level through workshops, mainly involving DWA officials. The level 3 RWQOs were determined by the DWA Gauteng Regional Office. Based on the criteria defined and the considerations identified, as well as the key drivers, RWQOs for the selected water quality variables for the Vaal River were determined. Recommendations were made during the study for the Development of an Integrated Water Quality Management Strategy for the Vaal River System (DWAF, 2009d) to include more water quality parameters in the RWQOs and also to decrease the limits of certain parameters to improve the water quality of the river in relation to nutrients.

Eco-specification relating to the ecological protection levels for TDS was also undertaken to ensure that the proposed RWQOs were aligned with, and took into consideration, the level of ecological protection required for the various reaches of the river. The ecology is a key component of the system, and the proposed RWQOs were generally stricter than the specified requirements.

No RWQOs for uranium were determined for the Blesbokspruit or Klip River catchments. The *South African Water Quality Guidelines* (1996a; 1996b; 1996c; 1996d; 1996e) set water quality targets for uranium only for the irrigation sector. These values are indicated in **Table 2.4**.

Table 2.4: Water quality guidelines for uranium for irrigation purposes

Variable	Measured as	Ideal	Acceptable	Tolerable	Unacceptable
Uranium	mg/ℓ	0.01	0.010 – 1.0	< 0.1	No value given

Table 2.5 shows the current water quality trends in the Blesbokspruit. Since the current RWQOs are based on the ‘acceptable’ level for water quality requirements, it can be concluded that although this catchment is ‘heavily used and impacted’, the vision is to improve the water quality to ‘acceptable’ levels. **Table 2.5** indicates which user requirements were the most sensitive for each water quality parameter. Livestock watering is not a water use with sensitive requirements for any of the parameters. The parameters set for recreation are based on physical rather than chemical parameters, except for pH which is the same as for all other water users.

Table 2.5: Blesbokspruit water quality requirements

Variable	Units	Ideal	Acceptable	Tolerable	Unacceptable	Most sensitive user*	Recreation	Livestock
Electrical Conductivity	mS/m	< 45	**45 – 70**	70 – 120	> 120	Industrial		
Alkalinity ($CaCO_3$)	mg/ℓ	< 40	**40 – 80**	80 – 120	> 120			
pH	-	6.5 – 8.5			< 6.5 or > 8.5		6.5 – 8.5	
Phosphate (PO_4)	mg/ℓ	< 0.2	**0.2 – 0.4**	0.4 – 0.6	> 0.6	Aquatic		
Sulphate (SO_4)	mg/ℓ	< 150	**150 – 300**	300 – 500	> 500	Industrial (Cat 2 – 3)		1 000
Nitrate (NO_3)	mg/ℓ	< 0.5	**0.5 – 3.0**	3.0 – 6.0	> 6.0	Aquatic		
Ammonia (NH_4)	mg/ℓ	< 0.1	**0.1 – 1.5**	1.5 – 5.0	> 5.0	Aquatic		
SAR		< 4	**4 – 8**	8 – 12	> 12	Irrigation		
Chloride (Cl)	mg/ℓ	< 80	**80 – 150**	150 – 200	> 200	Aquatic		1 500
Chemical oxygen demand (COD)	mg/ℓ	< 20	**20 – 35**	35 – 55	> 55	Aquatic		
Aluminium (Al)	mg/ℓ		**< 0.3**	0.3 – 0.5	> 0.5	Aquatic		10
Fluoride (F)	mg/ℓ	< 0.19	**0.19 – 0.70**	0.70 – 1.00	> 1.00	Domestic use		4
Iron (Fe)	mg/ℓ	< 0.1	**0.1 – 0.5**	0.5 – 1.0	> 1.0	Aquatic		50
Magnesium (Mg)	mg/ℓ	< 8	**8 – 30**	30 – 70	> 70	Irrigation		1 000
Manganese (Mn)	mg/ℓ	< 0.2	**0.2 – 0.5**	0.5 – 1.0	> 1.0	Domestic		50
Sodium (Na)	mg/ℓ	< 70	**70 – 100**	100 – 150	> 150	Irrigation		2 000
Algae	µg/ℓ Chl-a						30	

Note: These water quality requirements take all water users in the Suikerbosrant River catchment into consideration, using the most sensitive water use.
Source: DWAF (2009d)

The aim of the proposed changes to the RWQOs (DWAF, 2009d) was to achieve the requirements for salts. However, the RWQOs are ultimately dependent on those set for the Vaal Barrage. Thus, once the Vaal Barrage objectives have been confirmed and the Level 2 RWQOs set, the tributary RWQOs must be re-evaluated based on the varying user requirements. The RWQOs for the Suikerbosrant River are generally more lenient than those for the Vaal Barrage, and the tributary impacts significantly on the main stem river. Nutrient concentrations are also high, and stricter RWQOs are therefore proposed.

It can therefore be seen that a number of parameters will become stricter, but the parameters for sulphate and EC seem unlikely to change at this stage.

b) Klip River

RWQOs for the Klip River quaternary catchment (which includes the Klipspruit) were integrated with the RWQOs set for the Vaal River, as determined during the Vaal River IWQM Strategy Study (DWA, 2009a; 2009b). The development of the RWQOs during this study was done at a desktop level, through workshops involving mainly DWA officials. RWQOs for the selected water quality variables for the Vaal River were determined. A set of integrated RWQOs for total dissolved solids (TDS), phosphate and *E. coli (Escherichia coli)* was defined for the Vaal River main stem for each of the 14 river reaches. These must be complied with, and the RWQOs set for all the sub-catchments flowing into the main stem therefore also had to be considered.

Eco-specification relating to the ecological protection levels for TDS was also undertaken to ensure that the proposed RWQOs were aligned with, and took into consideration, the level of ecological protection required for the various reaches of the river. The ecology is a key component of the system, and in most cases the proposed RWQOs are stricter than the specified requirements.

The aim is to achieve the RWQOs for salts. However, the RWQOs are ultimately dependent on those set for the Vaal Barrage. It was suggested that once the RWQOs for the Vaal Barrage had been confirmed (DWAF, 2009d), these objectives must be reviewed, with due consideration for the varying user requirements.

The Vaal Barrage in the main stem of the Vaal River, into which both the Suikerbosrant and the Klip Rivers drain, is an impoundment ‘hotspot’ area, receiving high levels of pollution (*e.g.* high bacteria, algae, heavy metals, salts and nutrients) from the urban/industrial sector, including both point sources and diffuse sources.

The values for the water quality requirements (applicable to the most sensitive user) are described in **Table 2.6**.

Table 2.6: Klip River catchment-specific water quality guidelines

Variable	Units	Ideal	Acceptable	Tolerable	Unacceptable	Most sensitive user
Physical						
Electrical Conductivity	mS/m	< 80	80 – 100	100 – 150	> 150	Industrial
Dissolved oxygen (O_2)	mg/ℓ		> 6	5 – 6	< 5	Aquatic
pH	-	6.0 – 9.0			< 6.0 or > 9.0	
Suspended solids	mg/ℓ	< 20	20 – 30	30 – 55	> 55	
Organic						
Chemical oxygen demand (COD)	mg/ℓ	< 15	15 – 30	30 – 40	> 40	
Macro elements						
Ammonia (NH_4)	mg/ℓ	< 0.5	0.5 – 1.5	1.5 – 4.0	> 4.0	Aquatic
Chloride (Cl)	mg/ℓ	< 50	50 – 75	75 – 100	> 100	Aquatic
Fluoride (F)	mg/ℓ	< 0.19	0.19 – 0.70	0.70 – 1.00	> 1.00	Domestic
Iron (Fe)	mg/ℓ	< 0.5	0.5 – 1.0	1.0 – 1.5	> 1.5	Aquatic
Manganese (Mn)	mg/ℓ	< 1	1.0 – 2.0	2.0 – 4.0	> 4	Domestic
Nitrate (NO_3)	mg/ℓ	< 2	2.0 – 4.0	4.0 – 7.0	> 7	Aquatic
Phosphate (PO_4)	mg/ℓ	< 0.2	0.2 – 0.5	0.5 – 1.0	> 1.0	Aquatic
Sodium (Na)	mg/ℓ	< 50	50 – 80	80 – 100	> 100	Irrigation
Sulphate (SO_4)	mg/ℓ	< 200	200 – 350	350 – 500	> 500	Industrial Cat. 3

Source: DWAF (2009d)

Table 2.7 shows the current water quality trends in the Klip River. Since the current RWQOs are based on the ‘acceptable’ level for water quality requirements, it can be concluded that although this catchment is heavily used and impacted, the vision is to improve the water quality to acceptable levels.

Table 2.7: First-order assessment of the existing RWQOs for the Klip River

Variable	Units	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile	Proposed Changes to the RWQOs suggested in the Vaal River IWQM Strategy Study
Nitrate	mg/ℓ	1.205	3.25	4.35	5.2	6.58	0.3 – 3.0
Ammonia	mg/ℓ as N	0.01	0.05	0.1	0.4	0.9	0.1 – 0.3
Sulphate	mg/ℓ	117	140	160	193	229.6	None
Chloride	mg/ℓ	43.15	60.75	68	74	81.7	None
EC	mS/m	66.25	73	76	84.8	94.1	None
TDS	mg/ℓ	430.625	474.5	494	551.2	611.65	None
Phosphate	mg/ℓ as P	0.3	0.5	0.65	0.88	1.56	0.10 – 0.50
Aluminium	mg/ℓ						0.05 – 0.1
TP	mg/ℓ						0.15 – 1.0
TN	mg/ℓ						1.0 – 4.0
Faecal coliforms	#/100mℓ						500 – 2 500
Algae	µg/ℓ Chl-a						10 – 15

Source: DWAF (2009d)

Key to colour codes

Ideal	**Acceptable**	**Tolerable**	**Unacceptable**

The aim of the proposed changes to the current RWQOs for the Klip River was to achieve the RWQOs for salts (DWAF, 2009d). However, the RWQOs are ultimately dependent on those set for the Vaal Barrage. Thus, once the Vaal Barrage objectives have been confirmed, the tributary RWQOs must be re-evaluated based on the varying user requirements. The RWQOs for the Klip River are more lenient than those for the Vaal Barrage, and the tributary impacts significantly on the main stem river. Nutrient concentrations are also very high, and stricter RWQOs are therefore proposed. Local resource management will also be required. Similar to the comments made for the Blesbokspruit RWQOs, it can be seen that a number of parameters will become stricter, but the parameters for sulphate and EC seem unlikely to change at this stage.

c) Upper Crocodile River West

An intermediate level Reserve determination has been completed in the Crocodile River West. These must still be finalised according to the Water Resource Classification System which were published in the Government Gazette on 17 September 2010. RWQOs have already been determined, and should be considered when determining RQOs.

The Tweelopies Spruit falls within the Upper Crocodile River West catchment. It is a small tributary of the Rietspruit, which joins the Crocodile River upstream of the Hartbeespoort Dam. The ecological importance and sensitivity of this part of the Upper Crocodile River catchment is marginal or low (DWAF, 2005a). The technical work for a Reserve determination at an intermediate level has been done for the Crocodile River West, but has not yet been finalised by DWA. RWQOs have been developed for the Modderfonteinspruit, which flows into the Jukskei River, another tributary of the Crocodile River, but also forms part of the Upper Crocodile River.

Given the available information, it was assumed for this study that the RWQOs for the Tweelopies Spruit and the Modderfonteinspruit would not be very different, since the receiving body in both cases is the Hartbeespoort Dam. These values are indicated in **Table 2.8.**

Table 2.8: RWQOs for the Modderfonteinspruit

Variable	Measured as	Modderfonteinspruit	Most sensitive user
Nitrate	mg/ℓ	< 5	Aquatic
Ammonia as N	mg/ℓ	0.77	Aquatic
Phosphate as P	mg/ℓ	< 0.1	Aquatic
Aluminium	mg/ℓ	0.085	Domestic
Electrical conductivity	mS/m	< 75	Industrial
Total dissolved solids*	mg/ℓ	481	
Chloride	mg/ℓ	< 75	Aquatic
Sulphate	mg/ℓ	400	Industrial Category 3

**6.5 factor used for conversion of EC to TDS*

d) Summary of Resource Water Quality Objectives

The summary of the RWQOs used for evaluating the discharge of water to the resource are presented in **Table 2.9**.

Table 2.9: Summary of RWQOs used for evaluating the discharge of water to the resource

Variable	Units	Blesbokspruit	Klip River	Tweelopies Spruit
		Acceptable Range	Acceptable Range	
Nitrate	mg/ℓ	0.05 – 0.25	0.3 – 3	< 5
Ammonia as N	mg/ℓ	0.03 – 0.15	0.1 – 0.3	0.77
Phosphate as P	mg/ℓ	0.03 – 0.15	0.1 – 0.5	< 0.1
Aluminium	mg/ℓ	0.05 – 0.1	0.05 – 0.1	0.085
Total phosphate	mg/ℓ	0.05 – 0.1	0.15 – 1	
Total nitrate	mg/ℓ	0.25 – 0.5	1 – 4	
Algae	µg/ℓ Chl-a	10 – 20	10 – 15	
Electrical conductivity	mS/m	45 – 70	80 – 100	< 75
Total dissolved solids*	mg/ℓ	292.5 – 455	520 – 650	481
Faecal coliforms	#/100 mℓ	130 – 500	500 – 2 500	
Chloride	mg/ℓ	80 – 150	50 – 75	< 75
Sulphate	mg/ℓ	150 – 300	200 – 350	400

*6.5 factor used for conversion of EC to TDS

Source: DWAF (2009d)

2.3.3 Discharge of Water Containing Waste

Section 21(f) of the NWA (36:1998) requires a water use licence for “discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit”. This would apply to any discharges of the raw or treated AMD water into a watercourse.

The standards for discharge quality that will be linked to the licence will be determined based on the principles discussed below.

A water use licence may be issued for a maximum period of 40 years and must be reviewed by DWA at intervals of not more than five years in terms of Section 28 of the NWA (36:1998).

a) Principles for Discharge of Water to a Water Resource

In considering discharge locations, the AMD water abstracted from the three basins may, after appropriate treatment, be discharged at points where it would have the least impact on the natural environment from both a quality and quantity perspective. Treatment options are available that can potentially render final water quality that will not have an impact on the aquatic environment. However, discharging excessive volumes into a water resource on a continual basis will have an impact on the aquatic habitat and biota. The Klip River and Blesbokspruit are both perennial rivers due to continual discharges, whereas the Tweelopies Spruit is a non-perennial river. For similar reasons, wetlands are also vulnerable in terms of discharge water quality and hydraulic overloading.

DWA's hierarchy of best practice guidelines for water re-use and reclamation stipulate that in order to prevent water quality deterioration, the discharge of water containing waste into the natural environment should be avoided. If this is not achievable, then a precautionary approach is taken in which the water should comply with the standards prescribed and set by DWA. However, this could imply a differentiated approach. If the minimum requirements mentioned above are insufficient to ensure the fitness for use of the receiving water environment, then stricter standards will be enforced in accordance with the differentiated approach. Such disposal or discharge of water containing waste, or relaxation of compliance with the minimum requirements as a last resort, will only be allowed in terms of an authorisation (licence) if the receiving environment has the capacity to assimilate the additional waste load. Relaxation would have to be justified on the basis of technological, economic and socio-political considerations.

The differentiated approach takes account of catchment-specific conditions, including environmental conditions, and includes the determination of RQOs and/or RWQOs and the setting of standards that must ensure compliance with RQOs and/or RWQOs.

The TCTA Due Diligence Report (TCTA, 2011) proposed discharging neutralised AMD into rivers over the short term, as shown in **Table 2.10**.

Table 2.10: Proposed discharging of neutralised AMD over the short term

Basin	Sub-catchment	WMA
Eastern Basin	Blesbokspruit	Upper Vaal
Central Basin	Klipspruit	Upper Vaal
Western Basin	Tweelopies Spruit	Crocodile (West) and Marico

Source: TCTA (2011)

Table 2.11 compares the raw AMD water quality with the RWQOs set for the selected catchments. The quality of treated AMD should be high enough to ensure that the RWQOs are not violated, *i.e.* even though the quality of the AMD is worse than the RWQOs, the river system may have enough assimilative capacity to accommodate that quality and quantity of AMD and thus it does not necessarily mean that the RWQOs will be violated.

Table 2.11: Raw AMD from the various basins compared to the RWQOs for each discharge point

Parameter	Unit	Western Basin		Central Basin		Eastern Basin	
		Typical concentrations of AMD from the Western Basin	RWQOs for the Modderfonteinspruit applied to the Tweelopies Spruit	Typical concentrations of AMD from the Central Basin	RWQOs for the Klip River	Typical concentrations of AMD from the Eastern Basin	RWQOs for the Blesbokspruit
pH	@ 25°C	3.5		2.4		5.9	
Total dissolved solids	mg/ℓ	5 434	481	4 592	650	3 358	455
Electrical conductivity	(mS/m) @ 25°C	442	70	465	100	363	75
Ca	mg/ℓ	703		563		421	
Mg	mg/ℓ	–		258		165	
Na	mg/ℓ	227		171		264	
SO_4	mg/ℓ	3 623	400	3 062	350	2 289	300
Cl	mg/ℓ	-		146		254	
Acidity/Alkalinity	mg/ℓ	1 520		-		560	
Iron (Fe)	mg/ℓ	954		108		227	
Al	mg/ℓ	-	0.085	193	0.1	2.4	0.3

For these parameters it must be determined whether the discharge of AMD, whether raw or treated, will cause the RWQOs to be violated.
Source: TCTA (2011)

3 POTENTIAL USERS AND THEIR REQUIREMENTS

3.1 General Re-use Options for Wastewater

The use of raw or treated AMD is not primarily considered because of the additional quantity of water that can be introduced into the system. The use of AMD of any quality is considered as an option to solve, or at least partially solve, some of the challenges of reducing the salinity associated with AMD.

The challenge is that return flows from domestic, agricultural or industrial re-use may be returned to wastewater treatment works and the Vaal River System without any material salt load being removed, which puts pressure on the RWQOs of the Vaal and Crocodile (West) River systems, and potentially requires additional dilution releases from the Vaal Dam. The recommendation of options for use of raw or treated AMD must aim to protect the RWQOs of the river systems, thereby ultimately protecting the assurance of supply of the river systems.

The rationale, potential benefits and driving factors of wastewater re-use, as identified by the United Nations Environment Programme (UNEP & GEC, 2004), are summarised in **Table 3.1**. It is recognised that the re-use rationale primarily considers the re-use of treated sewage water and industrial wastewater in order to reduce potable water demand, rather than the re-use of AMD specifically, which is a less significant problem internationally than currently being experienced in South Africa.

Table 3.1: Wastewater re-use: rationale, potential benefits and factors driving its further use

Rationale for wastewater re-use:
• Water is a limited resource. Increasingly, society no longer has the luxury of using water only once; • Wastewater re-use more appropriately matches water use application with water resource quality, resulting in more effective and efficient use of water; and • The goal of water resource sustainability is more attainable when a wastewater re-use option is implemented.
Potential benefits of wastewater re-use:
Wastewater re-use conserves freshwater supplies: • Wastewater re-use increases the total available water supply. High-quality water supplies, such as for drinking water, can be conserved by substituting reclaimed water where appropriate.
Wastewater re-use is environmentally responsible: • Wastewater re-use can preserve the health of watercourses, wetlands, flora and fauna. It can reduce the level of nutrients and other pollutants entering watercourses and sensitive marine environments by reducing wastewater discharges.
Wastewater re-use makes economic sense: • Reclaimed water is available near urban development where water supply reliability is most crucial

and water is priced the highest.

Wastewater re-use can save resources:

- Reclaimed water originating from municipal wastewater contains nutrients; if this water is used to irrigate agricultural land, less fertiliser is required for crop growth. Reducing nutrient (and resultant pollution) flows into watercourses helps the tourism and fishing industries.

Factors driving further implementation of wastewater re-use:

- Proximity: Reclaimed water is readily available in the vicinity of the urban environment, where water resources are most needed and highly priced.
- Dependability: Reclaimed water provides a reliable water source, even in drought years, as the production of urban wastewater has low seasonal variability.
- Versatility: Technically and economically proven wastewater treatment processes are available that can provide water for non-potable and potable re-use.
- Safety: Non-potable water re-use systems have been in operation for over four decades with no documented adverse public health impacts in developed countries.
- Competing demands for water resources: Increasing pressure on existing water resources due to population growth and increased agricultural demand.
- Fiscal responsibility: Growing recognition among water and wastewater managers of the economic and environmental benefits of using reclaimed water.
- Public interest: Increasing awareness of the environmental impacts associated with over-use of water supplies, and community enthusiasm for the concept of wastewater re-use.
- Environmental and economic impacts of traditional water resources approaches: Greater recognition of the environmental and economic costs of water storage facilities such as dams and reservoirs.
- Proven track record: The growing number of successful wastewater re-use projects all over the world.
- Implementation of a cost-recovery approach to water pricing: The introduction of new water charging arrangements (such as full cost pricing) that more accurately reflect the full cost of delivering water to consumers, and the growing use of these charging arrangements.
- More stringent water quality standards: Increased costs associated with upgrading wastewater treatment facilities to meet higher water quality requirements for effluent disposal.
- Necessity and opportunity: Motivating factors for the development of wastewater re-use projects such as droughts, water shortages, prevention of sea water intrusion and restrictions on wastewater effluent discharges, as well as economic, political and technical conditions favourable to wastewater re-use.
- In the context of the Witwatersrand AMD problem, the treatment and re-use of AMD could materially reduce the pressure placed on the water available from the Lesotho Highlands that is required to dilute the increasing salinity of the Vaal River System , but only if the AMD salt loading to the system is sufficiently reduced.

Source: UNEP & GEC (2004)

The UNEP report on water and wastewater re-use categorised the various potential applications of wastewater re-use, as shown in **Table 3.2** in respect of urban re-use, agricultural re-use, recreational re-use and other re-use opportunities that could be considered including industrial, mining and domestic re-use, and environmental enhancement to offset potable water demand.

Table 3.2: Categories of wastewater re-use

Category of re-use	Description of category
Urban use	
Unrestricted irrigation	Landscape irrigation of parks, playgrounds, school yards, golf courses, cemeteries, residential areas, green belts.
Restricted irrigation	Irrigation of areas with infrequent and controlled access.
Other uses	Fire protection, disaster preparedness and construction.
Agricultural	
Food crops	Irrigation for crops grown for human consumption.
Non-food crops and crops consumed after processing	Irrigation for fodder, fibre, flowers, seed crops, pastures, commercial nurseries and instant lawn.
Recreational use	
Unrestricted body contact	No limitation on body contact: lakes and ponds used for swimming.
Restricted body contact	Fishing, boating and other non-contact recreational activities.
Other	
Environmental enhancement	Artificial wetland creation, natural wetland enhancement, stream flow.
Groundwater recharge	Groundwater replenishment for potable water, salt water intrusion control, subsidence control.
Industrial re-use*	Cooling system water, process water, boiler feed water, toilets, laundries, construction wash-down water, air conditioning.
Residential use	Cleaning, laundries, toilets, air conditioning.
Potable re-use	Blending with municipal water supply, pipe-to-pipe supply.

** See discussion below table with respect to mining and industrial use.*
Source: UNEP & GEC (2004)

It is expected that industrial water users will assess opportunities to minimise their water demands. It is also expected that they will seek opportunities to use available secondary quality water prior to assessing opportunities to recycle and re-use water, and also prior to assessing opportunities to treat water for re-use purposes, and disposing of excess water only as a last resort.

Large amounts of water are used (consumptively and non-consumptively) by the mining industry for transport of material (slurry), processing (washing, separation plants), control (cooling systems, boilers), *etc.* This water is abstracted directly (from boreholes, dams, streams or rivers) or indirectly (via a water services provider) from water resources (surface water and groundwater), and might place a strain on South Africa’s limited water resources.

Some of the raw water abstracted from the Vaal River System is lost, for example, through evaporation. Other raw water intake is contaminated during utilisation and therefore not fit for direct release/discharge back into the water resource from which it was taken. Given the growing demand for water and the scarcity of this natural resource, it is important for any mining operation to prove that water utilisation is optimised through re-use and reclamation of contaminated water. All new and existing mines are therefore required, in terms of the NWA (36:1998), National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA (107:1998)) and the Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA (28:2002)), to optimise water re-use and reclamation. From a conservation perspective, re-use and reclamation ensure effective and beneficial use of scarce water resources and overall environmental protection. The re-use of secondary quality water (*i.e.* treated AMD) on a mine may be preferred to extensive treatment schemes.

Many different water quality criteria and guidelines have been published in the international and local literature. Different approaches and methodologies have often been used to derive criteria and guidelines. For example, some guidelines specify maximum concentrations for constituents if the water quality is to be fit for use, whereas others attempt to define the ideal concentration of a constituent, often with the inclusion of safety factors. Therefore, depending on which guideline or criterion is used to establish water quality requirements, it is possible to arrive at answers that sometimes differ by a factor of hundred or more. The rationale for developing the *South African Water Quality Guidelines* (DWAF, 1996a; 1996b; 1996c; 1996d; 1996e) was to:

- Develop a single set of guidelines and criteria in water quality and fitness for use that is appropriate for South Africa, based on a consensus of South African expertise and other role players. The intention of this approach is to limit the confusion that often arises from the use of different criteria and guidelines to establish the water quality requirements for a particular water use by the stakeholders of water supply and utilisation in South Africa; and
- Modify international guidelines in the light of local research and experience.

The *South African Water Quality Guidelines for Domestic Water Use (DWAF, 1996a)* are essentially a user needs specification of the quality of water required for different domestic uses. The document is intended to provide the information required to make judgements as to the fitness of water to be used for domestic purposes, primarily for human consumption but also for bathing and other household uses. The guidelines are applicable to any water that is used for domestic purposes, irrespective of its source (municipal supply, borehole, river, *etc.*) or whether or not it has been treated.

The *South African Water Quality Guidelines for Industrial Water Use (DWAF, 1996b)* is essentially a user needs specification of the quality of water required for different industrial uses. It provides the information needed to make judgements as to the fitness of water to be used for industrial purposes. The guidelines are applicable to any water that is used for industrial purposes, irrespective of its source (municipal supply, borehole, river, *etc.*) or whether or not it has been treated.

The *South African Water Quality Guidelines for Irrigation Water Use (DWAF, 1996c)* is essentially a user needs specification of the quality of water required for different irrigation uses. It is intended to provide information to make judgements on the fitness of water to be used for irrigation purposes, primarily for crop production. The guidelines are applicable to any water that is used for irrigation purposes, irrespective of its source (municipal supply, borehole, river, *etc.*) or whether or not it has been treated.

The *South African Water Quality Guidelines for Livestock Watering Use (DWAF, 1996d)* is essentially a user needs specification of the quality of water required for different livestock production systems. It provides information to make judgements on the fitness of water for livestock watering purposes, primarily for consumption by livestock, but also for water distribution systems. The guidelines are applicable to any water that is used for livestock watering purposes, irrespective of its source (municipal supply, borehole, river, *etc.*) or whether or not it has been treated.

The *South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996e)* is essentially a specification of:

- The surface water quality required to protect fresh water aquatic ecosystems (the guidelines do not deal with marine and estuarine ecosystems);
- Quantitative and qualitative criteria for chronic and acute toxic effects for toxic constituents;
- Quantitative and qualitative criteria to protect ecosystem structure and functioning, for non-toxic constituents and system variables;
- Quantitative and qualitative criteria to protect aquatic ecosystems against changes in trophic status in the case of nutrients;
- Modifications that can be made to water quality criteria on a site-specific basis, whilst still providing the same level of protection as the original criteria.

The Target Water Quality Range (TWQR) for various parameters for the different users as given in the guidelines described above is shown in **Table 3.3** with respect to the primary AMD components. For more detail regarding the TWQR for the different users and the possible effects if parameter values fall outside the TWQR, refer to **Appendix B** or the South African Water Quality Guidelines discussed above.

Table 3.3: Comparison of the Target Water Quality Range values with respect to primary AMD components

Parameter	**Domestic use**	**Livestock watering**		**Aquatic ecosystems**	**Irrigation use**		**Industrial use**			
							User Category			
							1	**2**	**3**	**4**
pH	6.0 – 9.0	NS		pH variation of no more than 0.5 or 5% on background, whichever is more conservative	6.5 – 8.4		7.0 – 8.0	6.5 – 8.0	6.5 – 8.0	5 – 10
Conductivity as EC (mS/m)	< 45[1]	< 154[2]	Pigs, poultry and dairy	NS	40	Sensitive crops[4]	0 – 15	0 – 30	0 – 70	0 – 250
		< 308[2]	Horses, beef		270	Moderately tolerant crops[4]				
		< 769[2]	Sheep							
Sulphate as SO_4 (mg/ℓ)	0 – 200	0 – 1 000		NS	NS		0 – 30	0 – 80	0 – 200	0 – 500
Total dissolved solids (TDS) (mg/ℓ)	0 – 450	0 – 1 000	Pigs, poultry and dairy	No more than 15% change from normal cycle and no change in amplitude and frequency of cycles	260[3]	Sensitive crops[4]	0 – 100	0 – 200	0 – 450	0 – 1 600
		0 – 2 000	Horses, beef		1 755[3]	Moderately tolerant crops[4]				
		0 – 5 000	Sheep							
Calcium as Ca (mg/ℓ)	0 – 32	0 – 1 000		NS	NS		NS	NS	NS	NS
Magnesium as Mg (mg/ℓ)	0 – 30	0 – 500		NS	NS		NS	NS	NS	NS

<table>
<tr><th rowspan="3">Parameter</th><th rowspan="3">Domestic use</th><th rowspan="3">Livestock watering</th><th rowspan="3" colspan="2">Aquatic ecosystems</th><th rowspan="3" colspan="2">Irrigation use</th><th colspan="4">Industrial use</th></tr>
<tr><th colspan="4">User Category</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td rowspan="5">Total Cadmium (mg/ℓ)</td><td rowspan="5">0 – 0.005</td><td rowspan="5">0 – 0.010</td><td>Total Cadmium (mg/ℓ)</td><td>Water Hardness (mg $CaCO_3$/ℓ)</td><td rowspan="5" colspan="2">< 0.01</td><td rowspan="5">NS</td><td rowspan="5">NS</td><td rowspan="5">NS</td><td rowspan="5">NS</td></tr>
<tr><td>0.00015</td><td>< 60</td></tr>
<tr><td>0.00025</td><td>60 – 119</td></tr>
<tr><td>0.00035</td><td>120 – 180</td></tr>
<tr><td>0.0004</td><td>> 180</td></tr>
<tr><td>Chromium as Cr (mg/ℓ)[5]</td><td>VI: 0 – 0.05</td><td>VI: 0 – 1</td><td colspan="2">VI: < 0.007
III: < 0.012</td><td colspan="2">< 0.10</td><td>NS</td><td>NS</td><td>NS</td><td>NS</td></tr>
<tr><td>Cobalt as Co (mg/ℓ)</td><td>NS</td><td>0 – 1</td><td colspan="2">NS</td><td colspan="2">< 0.05</td><td>NS</td><td>NS</td><td>NS</td><td>NS</td></tr>
<tr><td rowspan="2">Iron as Fe (mg/ℓ)</td><td rowspan="2">0 – 0.1</td><td rowspan="2">0 – 10</td><td rowspan="2" colspan="2">≤10 % variation on background dissolved iron concentration</td><td>< 0.2</td><td>Clogging of irrigation equipment</td><td rowspan="2">0 – 0.1</td><td rowspan="2">0 – 0.2</td><td rowspan="2">0 – 0.3</td><td rowspan="2">0 – 10</td></tr>
<tr><td>< 5</td><td>Crop yield and quality</td></tr>
<tr><td rowspan="2">Manganese as Mn (mg/ℓ)</td><td rowspan="2">0 – 0.05</td><td rowspan="2">0 – 10</td><td rowspan="2" colspan="2">< 0.18</td><td>< 0.02</td><td>Crop yield and soil sustainability</td><td rowspan="2">0 – 0.05</td><td rowspan="2">0 – 0.1</td><td rowspan="2">0 – 0.2</td><td rowspan="2">0 – 10</td></tr>
<tr><td>< 0.1</td><td>Clogging of irrigation equipment</td></tr>
</table>

1 - As per the guidelines for TDS
2 - Calculated from TDS values using a conversion factor of 1/6.5 to convert from mg/ℓ to mS/m.
3 - Calculated from EC values using a conversion factor of 6.5 to convert from mS/m to mg/ℓ.
4 - Crops sensitive to total dissolved solids/electrical conductivity include fruit, almonds, root vegetables (except beet), maize, sunflowers and rice. Tolerant crops include asparagus, sugarbeet, sorghum, oats, wheat and rye.
5 - III and VI refer to the different variations of the Chromium ion, in this case the Chromite ion and the Dichromate ion respectively.
NS - Not Specified

References: DWAF (1996a; 1996b; 1996c; 1996d; 1996e ;1999)

The re-use options that were identified that are applicable to the Witwatersrand catchments, either for raw AMD, partially treated AMD (*i.e.* pH neutralised and heavy metals removed by means of conventional High Density Sludge (HDS) treatment) or treatment to a higher quality standard (*i.e.* desalination as applied at the eMalahleni AMD treatment plant) in the Witwatersrand region are discussed below.

3.1.1 Treated AMD Re-used Domestically

Although it is recognised that full-scale potable supply from treated AMD has both quality and social challenges (because of negative public perceptions), the success of the eMalahleni experience has demonstrated that it can be viable to treat AMD to a quality that can be integrated directly into a municipal water supply (Hutton *et al*., 2009).

As with the re-use of treated sewage being practised in Cape Town and Durban, partially treated AMD, rather than meeting potable quality, could supplement the existing potable water supply for water uses that do not require potable water quality, such as some industrial process water uses, or at the household or business level for flushing toilets, cleaning, *etc.* This re-use option could be implemented on a small scale, either in association with treated sewage, or independently, as a case study to test its viability prior to full-scale implementation in an applicable urban area.

The re-use of only partially treated AMD (*i.e.* pH neutralised and metals removed as provided for in the STI), inherently implies that the majority of the salt load will still be present and entering the Vaal, Crocodile and Olifants river systems, through the domestic sewerage systems, which would not materially reduce the salt load. Consequently, partial treatment for domestic re-use does not materially change the current status of the STI, but would require material costs to provide such secondary quality water to domestic users.

3.1.2 Industrial Re-Use

As with the qualification noted above, it is recognised that an acceptable water quality for the applicable industry is not the only consideration when determining the re-use of AMD (treated or otherwise). The main concern is the removal of salts from the system so that there would be no need to use dilution water. Unless industrial re-use end in a salt sink and substitute the use of good quality water, it would not contribute to solving the main problem (salt load) of the AMD. On the other hand, there may be industries that require desalinated AMD, in which case the salts are removed before use.

In 1991, the National Survey of Industrial Water and Wastewater (NATSURV), undertaken for the Water Research Commission (WRC) and the Department of Water Affairs and Forestry (DWAF) (WRC, 1991) surveyed more than 530 individual industrial water users, 218 of which were in the Vaal River water supply area, representing premises using more than 50 m^3/d (0.05 Mℓ/d) for industrial purposes.

The 218 separate premises carried out 31 distinct industrial activities, representing a total water intake of 289 Mℓ/d, whilst three super-factories in the Vaal River catchment area were responsible for 67% of the total industrial water intake. A further 10 industry groups accounted for a further 28% of the total industrial water intake. The industries and their daily water intake are tabulated in **Table 3.4**. In the case of exclusive supply to the smaller industries, a dedicated conveyance system would be required, and since such industries are often not all situated in a common location, such as in an industrial park, the delivery of treated AMD poses a challenge. Where it is possible for multiple smaller industries to utilise neutralised AMD, the salt-load is to be "diffused", making its "containment" difficult and impairing management thereof.

The practical industrial water intakes and discharges may have changed over time, but the principal findings remain applicable to the current study. Whilst there are many industries located within the Rand Water supply area, the vast majority represent industrial water users of less than 50 m^3/d (0.05 Mℓ/d); two-thirds of the industrial water demand is made up by three individual operations, substantially distant from the AMD generation points; and all primary industrial water users require good quality water at an even higher standard than potable water standards, which is not provided by untreated or neutralised AMD.

Table 3.4: Industrial water intake in the Vaal Barrage catchment area

Industry	No. of industries surveyed	Water intake (m^3/d)
Chemicals	31	37 858
Plating	51	7 260
Printing and publishing	5	191
Banking	6	441
Photographic	1	150
Soft drinks	8	4 245
Sorghum beer	7	1 325
Motor trade	18	1 037
Malt brewing	2	9 125
Tanning and leather	4	981
Food miscellaneous	9	3 080
Rubber and plastic	6	1 027
Dairy	7	930
Laundry	7	2 203
Vegetable oils	2	1 480
Paper products	7	5 510
Glass and glass products	4	1 027
Fruit and vegetables	4	3 595
Synthetic diamonds	1	148
Pulp and paper	2	678
Concrete	7	403

Industry	**No. of industries surveyed**	**Water intake (m^3/d)**
Iron and steel	9	3 687
Motor vehicles	1	138
Grain	1	300
Pottery	2	318
Non-ferrous metals	1	118
Gas	1	229
Vehicle depots	2	181
Meat	7	4 757
Tobacco products	2	717
Bricks, tiles, clay and pipes	3	656
	218 industries surveyed	93 808
Super-factory 1		32 000
Super-factory 2		68 000
Super-factory 3		95 000
Total industrial water use		288 808

Source: WRC (1991)

The wide variety of industries and the small amount of water that they use (compared to the volume of AMD), proves that it will be very difficult to exclusively supply treated AMD to smaller industries, even if these are locally situated. Providing individual delivery pipelines to more industries will lead to higher capital, operation and maintenance expenditure than a single pipeline to one bulk user.

Rand Water has identified plans to boost industrial water supply, driven by a strong demand from mines and industries, and including the use of secondary quality water for industrial water. Many mines and plants, such as power stations, could use substantially less fully purified potable water. Rand Water's 2007 annual report (Rand Water, 2007) gives an example of how water could be extracted from the Hartbeespoort Dam and purified to a standard suitable for industrial use that could be pumped to mines between Madibeng and Rustenburg and possibly to Lephalale to provide industrial consumers with industrial grade water. Treated AMD could be considered as a similar source of secondary water.

However, as with the re-use of partially treated AMD for domestic purposes, the re-use of only partially treated AMD for industrial purposes (*i.e.* pH neutralised and metals removed) inherently implies that the majority of the salt load will still be present and entering the surface water resources (and possibly groundwater resources), where industrial re-use would not materially reduce the salt load. Consequently, partial treatment for industrial re-use might not materially change the current status of the STI measures, but would require material costs to provide such secondary quality water to industrial users, and would diffuse the AMD salt loading, which can currently be viewed as point source pollution.

Although there is some localised use of groundwater in the Rand Water supply area from shallow groundwater systems and the dolomitic aquifer south of the Witwatersrand, currently, industrial water use is primarily sourced from Rand Water and associated potable water supplies. This indicates the general requirement for good quality water for production and processing purposes. However, it may be recognised that industries generally do not have ready access to alternative water sources to that supplied by Rand Water and associated service providers, and may be obliged to use potable water when water of secondary quality might suffice. Some mines do re-use treated sewage effluent as process water make-up, and Sappi Enstra has re-used treated municipal effluent as process water make-up. There are probably a number of other localised examples of treated sewage re-use as a secondary water quality replacement to potable water.

In the guidelines, industries are defined as systems of water-using processes, in which the fitness for use of the water is assessed in terms of the following criteria associated with the potential to use such water:

- its potential for causing damage to equipment (for example, corrosion, abrasion);
- problems it may cause in the manufacturing process (for example, precipitates, colour changes);
- impairment of product quality (for example, taste, discolouration); and
- complexity of waste handling as a result of using water of the quality available.

Four categories of industrial processes have been defined according to the degree of water purity or tightness of specification for the required water quality, as outlined in **Table 3.5** below.

Table 3.5: Categories for industrial processes using water

Category 1
Processes that require a high-quality water with relatively tight to stringent specifications of limits for most or all of the relevant water quality constituents. Standard or specialised technology is essential to provide water conforming to the required quality specifications. Consequently, costs of in-house treatment to provide such water are a major consideration in the economy of the process.
Category 2
Processes that require water of a quality intermediate between the high quality required for Category 1 processes and domestic water quality (Category 3 processes). Specifications for some water quality constituents are somewhat tighter or more stringent than required for domestic water quality. Standard technology is usually sufficient to reach the required water quality criteria. The cost for such additional water treatment begins to be significant in the economy of the process.
Category 3
Processes for which domestic water quality is the baseline minimum standard. Water of this quality may be used in the process without further treatment, or minimum treatment using low to standard technology may be necessary to reach the specifications laid down for a desired water quality. Costs of further in-house treatment are not significant in the economy of the process.
Category 4
Processes within certain limitations can use water of almost any quality for their purposes without creating any problems. Generally, no additional treatment is required, and there is therefore no further cost.

From **Table 3.5** it can be concluded that only Category 4 industrial processes might be capable of using neutralised AMD and the options for this is limited. Raw AMD cannot be considered for any of the industrial use categories listed above. Desalinated AMD, if treated to a high enough standard to be considered domestic water quality, will be suitable for Category 3 industrial processes. Categories 1 and 2 require a higher water quality than domestic water quality and thus further treatment than what is currently envisaged will be required. The extra costs associated with attaining the higher quality water required for Categories 1 and 2 industrial processes might outweigh the benefits of supplying users in these categories, in which case supply to users in Categories 3 and 4 will be preferred.

A primary concern with the on-going discharge and seepage of AMD into the Vaal River System is the increasing salinity, and the increasing risk to industrial water systems posed by sulphate reduction (and chloride and sodium *etc.*), associated infrastructure corrosion, sulphate and calcium (and magnesium) infrastructure scaling, and residual metals and nutrients. This detrimentally affects the industrial products, which is of specific relevance to the food and beverage industry, chemical and petro-chemical industries and power generation, but extends to most industrial water users.

Industry processes requiring particular water quality types are given in **Table 3.6**.

Table 3.6: Industry processes requiring particular water qualities

Process	Process type	Water use
Category 1	Cooling water	Evaporation cooling (high recycling)
	Steam generation	High pressure (HP) boiler: demineralisation of feed water
	Process water	Phase separation
		Petrochemicals
	Product water	Pharmaceuticals
	Wash water	No residual washing (electronic parts)
Category 2	Cooling water	Evaporative cooling (high recycle)
		Solution cooling
		Water heating
	Steam generation	HP boiler: demineralisation feed
		Solvent
		Heat transfer medium
		Humidification
		Lubrication
		Gas cleaning
	Product water	Beverages
		Dairy products
		Petrochemicals
	Wash water	Reaction vessel washing

Process	Process type	Water use
Category 3	Cooling water	Evaporative cooling (once through)
		Bearing cooling
		Mould cooling
	Steam generation	Low pressure (LP) boiler (softener feed)
	Process water	Solvent
		Dilution agent
		Transport agent
		Gland seal
		Vacuum seal
		Lubrication
		Descaling (iron and steel)
		Gas scrubbing
	Product water	Beverages
		Food products
		Baking
		Confectionery
		Chemicals
		Surface washing (table tops, walls)
	Utility water	Domestic use
		Fire fighting
Category 4	Cooling water	Ash quenching
	Process waters	Transport agent
	Utility water	Dust suppression
		Fire fighting
		Irrigation
	Wash water	Rough washing (floors, rough apparatus, trucks, raw materials)

Potential water-related problems associated with various industrial processes are indicated in **Table 3.7**.

Table 3.7: Potential water-related problems associated with various industrial processes

Process type	Equipment damage	Process problems	Product problems	Waste disposal[1]
Cooling water	• Corrosion • Scaling • Fouling • Blockages	• Foaming • Sediments • Gas production • Odours	-	• pH • TDS • COD[2]

Process type	**Equipment damage**	**Process problems**	**Product problems**	**Waste disposal**[1]
Water for steam generation	• Resin film • Resin poison • Corrosion • Scaling	• Resin impairment • Competition	• Inadequate treatment	• pH • TDS
Process water	• Corrosion • Scaling • Fouling • Blockages • Abrasion • Embrittlement • Discolouration	• Precipitates • Foaming • Colour effects • Gas production • Interference	• Sediment • Foam • Colour • Taste/odour • Tarnish	• SS[3] • Fe/Mn • TDS
Product water	• Corrosion • Scaling • Fouling • Blockages	• Precipitates • Foaming • Gas production • Interference	• Sediment • Turbidity • Foam • Colour • Taste/odour • Coagulation	-
Utility water	• Corrosion • Scaling • Fouling • Blockages • Abrasion	-	• Sediment • Turbidity • Foam • Colour • Taste/odour • Intestinal irritation • Health hazards	• pH • TDS • SS • Fe/Mn • COD
Wash water	• Corrosion • Scaling • Fouling • Blockages • Abrasion	• Contamination	• Contamination • Blemishes • Sediment • Process solutions	• pH • TDS • SS • Fe/Mn • COD

1 *Refer to DWA AMD FS 2013, Study Report No. 5.4: “**Treatment Technology Options**” for more information on the composition of the residues from treatment processes.*

2 *Chemical Oxygen Demand.*

3 *Suspended Solids*

The water quality problems listed in **Table 3.7** often relate to a specific constituent that causes the problem. Frequently, water quality problems are associated not only with certain parameters, but with the interaction between parameters, as in the case of corrosion and scaling. **Table 3.8** below indicates the constituents that may be associated with specific water-related problems in industrial processes.

Table 3.8: Constituents in water that contribute to industrial water use problems

Parameter	Constituents										
	pH	**Cond**	**TH***	**Fe**	**Mn**	**Alk**	**SO_4**	**Cl**	**SiO_2**	**SS**	**COD**
Corrosion*	x	x	x	x		x	x	x		x	x
Scaling*	x	x	x	x		x	x		x	x	
Fouling				x	x					x	x
Blockages	x	x	x	x	x	x	x		x	x	x
Abrasion							x			x	
Embrittlement	x	x						x			
Discolouration	x			x	x						x
Resin blinding	x	x	x	x	x	x	x		x	x	
Foaming	x					x					x
Sediment	x		x	x	x		x			x	
Gas production	x					x	x				x
Taste/odours	x	x		x	x			x			
Precipitates	x	x	x	x	x	x	x				
Turbidity	x			x			x			x	x
Colour	x			x	x						x
Biological growth	x			x	x	x	x			x	x

***** *Although it is the calcium component of the total hardness (mainly Ca^{2+} plus Mg^{2+}) that is commonly implicated in scaling and corrosion problems, a guideline for total hardness is given, since softening procedures usually remove total hardness rather than calcium alone.*

Most of the water quality impacts on industrial water use identified in **Table 3.8** would remain as issues or impacts after partial treatment of AMD, though possibly at a less severe level, where pH neutralisation and some metals reduction is provided by the conventional HDS process that forms part of the STI. Salinity would remain a potential corrosion, scaling and blockage threat. Some metals and suspended solids, and possibly organics and nutrients, might remain as colour, turbidity, biological growth, fouling, discolouration, resin blinding, *etc.*

The *Best Practice Guideline for Water Resource Protection in the South African Mining Industry, H3, Water Re-Use and Reclamation* (DWAF, 2006a) provides specific guidance on the re-use of secondary quality water rather than potable water in the mining industry. It is recognised that re-use has a place in the DWA hierarchy for decision-making as well as in the NWA (36:1998) and the NEMA (107:1998).

3.1.3 Re-use for Watering Parks, Gardens and Sports Facilities

Irrigation of sports facilities, golf courses and other grounds requires high volumes of water at lower quality than potable water quality, for which treated AMD as well as treated sewage effluent could be a potential source. Certain towns have designed their systems to make the re-use of treated sewage effluent on parks, gardens and roadways possible within the immediate vicinity of the municipal wastewater treatment works, recognising that the extension of this re-use option would involve extending the pipeline infrastructure to more distant parks, gardens and roadways.

It should be noted that the considerations for this re-use would conceptually be very similar to re-use by irrigation and that the re-use of neutralised AMD for water parks, gardens and sports facilities is not equivalent to re-use with reclaimed sewage, with the neutralised AMD having a predominantly saline and low nutrient character, and the reclaimed sewage a predominantly nutrient character, with associated organics and microbial considerations.

However, the amount of water that could be used in this way would be very small in the context of the whole Witwatersrand AMD problem and the logistics of supplying parks, gardens and roadways in towns and cities with treated AMD is not considered viable. The cost of a separate pipeline would also be considerable, and does not remove the full salt load from the system, even when compared with the cost of desalination to reduce the salt load from the system, as well as an addition to the saving in water cost.

The areas required to utilise the treated AMD would be substantial and not readily available as parks, gardens and roadways. Additional constraints, that potentially could be managed with an appropriate control system include that irrigational control would be required to prevent run-off of treated AMD returning a substantial portion of the salt load to the river systems (*i.e.* from a point source of pollution to a diffuse source), a secondary network of pipes that would be required will be costly, and as with treated sewage, it would be difficult to stop the public from accessing this water and drinking it, thus resulting in a potential public health risk. Although the health risk associated with drinking neutralised AMD may be considered potentially less than drinking reclaimed sewage, it would be difficult to challenge the cause of any ailment suffered by persons drinking the affected water, and public reputation could be compromised.

The level of treatment also need to be considered as high salinity water could contribute to the detriment of the soils that may lead to leakage of salts to groundwater and cause damage to the flora of the parks, which may subsequently require further use of potable water to flush accumulated salts from the soil system.

3.1.4 Agricultural Re-use: Irrigation

It is recognised that neutralised and desalinated AMD from the Witwatersrand catchments could be re-used in existing, irrigation schemes for salt-tolerant crops, as well as in extended and new schemes. The supply of treated AMD to large irrigation schemes could be considered, since the reticulation infrastructure is already in place, apart from transporting water to the irrigation scheme intake. Such re-use of treated AMD has occurred in the past when neutralised AMD was discharged into the Blesbokspruit and then abstracted for irrigation, although it is noted that the AMD would have been diluted to some extent by the other water within the Blesbokspruit, as well as by rainfall, run-off and treated sewage discharges.

Neutralised AMD (not desalinated) from coal mines have been used for more than 10 years under commercial farming conditions in Mpumalanga to successfully irrigate a wide range of crops as part of a WRC research project in association with Coaltech. This research proved that crops cannot only be successfully irrigated with neutralised AMD, but that the soil also acts as a salt sink in that a major portion of the salts (in the form of gypsum) is precipitated within the soil and thus removed from the water environment. It must however be noted that there is no assurance that in the long-term the salts will not dissolve and re-enter the groundwater and surface water systems, since the research has only been conducted in the short/ medium-term. This is discussed in more detail in **Chapter 5**.

Water quality has a dramatic effect on soil productivity and crop health. The major water quality parameters for crop irrigation include salinity, sodium adsorption ratio (SAR), pH, alkalinity (carbonate and bicarbonate) and concentrations of specific ions (*i.e.* chloride, sulphate, boron and nitrate-nitrogen (NO_3-N). Other water constituents that may affect suitability for agricultural use include heavy metals and microbial contaminants.

The United Nations Food and Agriculture Organisation (FAO, 1985) suggests various water quality criteria for general irrigation[5]. The water quality characteristics of AMD can be compared to generally accepted irrigation water quality requirements.

The guidelines and crop salinity tolerance values are sufficient to make reliable estimates of soil and crop responses to the use of wastewater, where the primary limitation is the chemical constituent, such as the total dissolved solids, relative sodium content and toxic ions.

Soil scientists use the following categories to describe irrigation water effects on crop production and soil quality:

- Salinity hazard: total soluble salt content;
- Sodium hazard: relative proportion of sodium to calcium and magnesium ions;
- pH: acid or basic;
- Alkalinity: carbonate and bicarbonate; and
- Specific ions: chloride, sulphate, boron and nitrate.

Microbial pathogens are another potential irrigation water quality impairment that may affect suitability for cropping systems.

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[5] http://www.fao.org/docrep/003/T0234E/T0234E00.htm#TOC

a) Salinity Hazard

The most influential water quality guideline on crop productivity is the water salinity hazard, as measured by electrical conductivity (EC) (**Table 3.9**). The primary effect of water with high EC on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants, even though the soil may appear wet[6]. Because plants can only transpire 'pure' water, usable plant water in the soil solution decreases dramatically as EC increases.

Actual yield reductions from irrigating with high EC water vary substantially. The factors that influence yield reductions include soil type, drainage, salt type, irrigation system and management.

Table 3.9: General guidelines for salinity hazard of irrigation water based on electrical conductivity

Limitations for use	Electrical conductivity
	(mS/m)
None	≤ 75
Some	75 – 150
Moderate[1]	150 – 300
Severe[2]	> 300

[1] Leaching required at higher range.
[2] Good drainage needed, and sensitive plants may have difficulty at germination.

The amount of water transpired through a crop is directly related to yield therefore irrigation water with high EC reduces yield potential. Beyond the immediate effects on the crop is the long-term impact of salt loading of the irrigation water. Water with an EC of only 115 mS/m contains approximately 2 000 pounds of salt for every acre foot of water (0.74 kg/m^3). The conversion factors in **Table 3.10** can be used to calculate potential yield reduction from saline water for selected crops at other EC levels. Irrigation guidelines are presented in **Table 3.11**.

Table 3.10*:* Potential yield reduction from saline water for selected irrigated crops[1]

	Yield reduction (%)			
Crop	**0**	**10**	**25**	**50**
	EC[2]			
Barley	530	670	870	1 200
Wheat	400	490	640	870
Sugarbeet[3]	470	580	750	1 000
Alfalfa	130	220	360	590
Potato	110	170	250	390

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[6] Bauder et al (2011): http://www.ext.colostate.edu/pubs/crops/00506.html

	Yield reduction (%)			
Crop	**0**	**10**	**25**	**50**
	EC[2]			
Corn (grain)	110	170	250	390
Corn (silage)	120	210	350	570
Onion	80	120	180	290
Dry beans	70	100	150	240

[1] Adapted from Ayers (1977)
[2] EC = electrical conductivity of the irrigation water in mS/m at 25°C.
[3] Sensitive during germination. EC should not exceed 3 dS/m for garden beets and sugarbeets.

Table 3.11*:* Irrigation guidelines

Parameter	Possible impacts above guideline values	DWAF irrigation		Canadian	Other (American States, Australian[2])	
					Value	Source
pH	Foliar damage, affects bio-availability of plant nutrients and potentially toxic constituents in soil.	6.5 – 8.4		NS		
Conductivity as EC (mS/m)	Increases salinity in soils resulting in decreased growth of plants.	< 40	Sensitive crops[1]	77 – 539 (calculated)	< 385 (calculated)	South Dakota
		< 270	Moderately tolerant crops[1]			
Sulphate as SO_4 (mg/ℓ)		NS		NS	NS	
Total dissolved solids (TDS) (mg/ℓ)	Increases salinity in soils resulting in decreased growth of plants.	< 260	Sensitive crops[1]	500 – 3 500	< 2 500	South Dakota
		< 1 755	Moderately tolerant crops[1]			
Total suspended solids (TSS) (mg/ℓ)	Decreases crop yields. Clogs irrigation systems.	< 50		NS	NS	
Calcium as Ca (mg/ℓ)		NS		NS	NS	
Magnesium as Mg (mg/ℓ)		NS		NS	NS	
Iron as Fe (mg/ℓ)	Iron deposits reduce crop yields. Clogs irrigation systems.	< 0.2	Equipment	< 5	NS	
		< 5	Crops			
Manganese as Mn (mg/ℓ)	Sensitivity varies. Clogs irrigation systems.	< 0.02	Crops	< 0.2	NS	
		< 0.1	Equipment			

Notes:
Canadian guidelines assume 1 000 mm application rate of water per annum and retention of trace ions in surface 15 cm of soil.
1: Crops sensitive to total dissolved solids/electrical conductivity include fruit, almonds, root vegetables (except beet), maize, sunflowers and rice. Tolerant crops include asparagus, sugarbeet, sorghum, oats, wheat and rye.
2: Extracted from discussions in Canadian Council of Resource and Environment Ministers (1987), where Australian Guidelines were referenced as Hart (1974).
References: DWAF (1996c); Canadian Council of Resource and Environment Ministers (1987); US Environmental Protection Agency (1980)

3.1.5 Agricultural Re-use: Livestock Watering

Some of the neutralised and desalinated AMD could be utilised to supplement livestock watering in that, as with the existing re-use of AMD discharged to river systems, livestock are accessing the treated and untreated AMD that is currently entering the surface water courses in the region, whilst recognising that livestock watering may not materially remove the salt load from the water environment. It is noted that the raw and neutralised AMD does not generally meet the *South African Water Quality Guidelines for Livestock Watering* (DWAF, 1996d) unless diluted, as occurs for current discharges in the Blesbokspruit, where water is informally used for stock watering.

Animals are able to ingest a wide variety of different water qualities without adverse health effects. However, highly saline water or water containing toxic chemicals may be hazardous to animals and may even render the milk or meat unfit for consumption. It must also be noted that supplying neutralised AMD for livestock watering will not suitably remove salts from the environment, *i.e.* the Vaal River System.

In evaluating the suitability of treated water for livestock watering, a number of factors should be considered, including water quality, local conditions, the availability of alternative supplies, seasonal changes, and the age and health condition of the animals. The FAO (1985) established a water quality guide for livestock and poultry uses[7], taking into consideration these factors and the need to minimise the risk of economic losses. The basic FAO guidelines should be met at all times. Local factors, such as the effects of evaporation and concentration, must sometimes also be considered. In arid and semi-arid regions, the water quality values for livestock watering may be higher than the basic FAO guidelines.

An adequate and safe water supply is essential to the production of healthy livestock and poultry. Water that adversely affects the growth, reproduction or productivity of livestock and poultry cannot be considered suitable**.** **Table 3.12** to **Table 3.15** show the recommended limits of certain pollutants and other substances commonly found in water used for livestock and poultry.

Table 3.12: Desired and potential levels of pollutants in livestock water supplies

Substance	Desired range	Problem range
pH	6.8 to 7.5	< 5.5 or > 8.5
Dissolved solids (mg/ℓ)	< 500	> 3 000
Total alkalinity (mg/ℓ)	< 400	> 5 000
Sulphate (mg/ℓ)	< 250	> 2 000

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[7] http://www.fao.org/docrep/003/T0234E/T0234E00.htm#TOC

Table 3.13: Safe upper limits for several substances that may be contained in water for livestock and poultry

Substance	Safe upper limit of concentration
Total dissolved solids	10 000 ppm
Magnesium + sodium sulphates	5 000 ppm
Alkalinity (carbonate + bicarbonate)	2 000 ppm

Table 3.14: Effect of salinity of drinking water on livestock and poultry

Soluble salt (mg/ℓ)	Effect
< 1 000	Low level of salinity; presents no serious burden to any class of livestock or poultry.
1 000 – 2 999	Satisfactory for all classes of livestock and poultry; may cause temporary mild diarrhoea in livestock and water droppings in poultry at higher levels; no effect on health or performance.
3 000 – 4 999	Satisfactory for livestock; may cause temporary diarrhoea or be refused by animals not accustomed to it; poor water for poultry causing watery faeces and, at high levels, increased mortality and decreased growth (especially in turkeys).
5 000 – 6 999	Reasonably safe for dairy and beef cattle, sheep, swine and horses; avoid use for pregnant or lactating animals; not acceptable for poultry, as it causes decreased growth and production or increased mortality.
7 000 – 10 000	Unfit for poultry and swine; risk in using for pregnant or lactating cows, horses, sheep, the young of these species, or animals subjected to heavy heat stress or water loss; use should be avoided, although older ruminants, horses, poultry and swine may subsist for long periods under conditions of low stress.
> 10 000	Risks are great; cannot be recommended for use under any conditions.

Table 3.15: Livestock watering guidelines in respect of AMD components (treated or neutralised)

Parameter	Possible impacts above guideline values	DWAF		Canadian	Other (American States, Australian[1])	
					Value	Source
pH	< 5.0 and > 9.5: irritation of mucous membrane	NS		NS	6.0 – 9.0	Tennessee
					6.5 – 9.0	Utah
Conductivity as EC (mS/m)	Calculated from TDS (TDS in mg/ℓ/6.5)	154	Pigs, poultry	462	38 – 2 615 (maximum allowable range)	Nebraska
		308	Dairy, horses		615	South Dakota
		769	Beef, sheep		462	Australia
Sulphate as SO_4 (mg/ℓ)	Diarrhoea and poor productivity, but temporary until stock have adapted. Higher concentrations may be tolerated without adverse effects.	1 000		1 000	1 000	Australia
Total dissolved solids (TDS) (mg/ℓ)	Decreased intake of water due to unpalatability and subsequent decrease in feed intake (dehydration induced hypophagia), diarrhoea, salt poisoning. May adapt to higher concentrations without adverse effects.	1 000	Pigs, poultry	3 000	250 – 17 000 (maximum allowable range)	Nebraska
		2 000	Dairy, horses		4 000	South Dakota
		5 000	Beef, sheep		3 000	Australia
Calcium as Ca (mg/ℓ)	Adverse chronic effects such as hypercalcaemia, decline in water and feed intake. May adapt to higher concentrations without adverse effects.	1 000		1 000	1 000	Australia
Magnesium as Mg (mg/ℓ)	Upsets calcium and potassium metabolism causing lethargy, loss of co-ordination, diarrhoea and decreased feed intake; but ruminant stock may adapt to concentrations up to 1 000mg/ℓ.	500		NS	NS	
Iron as Fe (mg/ℓ)	Vomiting, diarrhoea, acidosis, shock and respiratory failure, liver and pancreas damage.	10		NS	NS	
Manganese as Mn (mg/ℓ)	Weight loss and anaemia but deficiencies are more likely.	10		NS	NS	

***Notes**:*
The 95th percentile or median values for water quality results should be compared to the guideline values, depending whether acute or chronic impacts are being looked at respectively.
Effects in livestock are less likely if exposure is short term, nutrient intake is adequate and feed concentrations are normal.
1. Extracted from discussions in Canadian Council of Resource and Environment Ministers (1987), where Australian Guidelines were referenced as Hart (1974) 2. 6.5 factor used for conversion of EC to TDS

References: DWAF (1996d); Canadian Council of Resource and Environment Ministers (1987); US Environmental Protection Agency (1980)

Desalinated AMD would be acceptable for stock watering, but requires either release into the river systems so that the water can be conveyed to the users via the river, or the installation of reticulation infrastructure to users.

3.1.6 Summary of Potential for Use of Partially Treated AMD

Table 3.16 summarises four categories of re-use, examples of specific application, the potential for AMD to be used in these applications, and the risks inherent in using AMD.

Table 3.16: Category of re-use, examples of applications, potential for AMD and risk in re-use

Industry	**Mining**	**Urban/Domestic**	**Agriculture**
Cooling water: Ash quenching Process waters: Transport agent Utility water: Dust suppression; Fire fighting; Irrigation: Wash water rough washing (floors, rough apparatus, trucks, raw materials). **Conclusion** The potential within the vicinity of AMD abstraction and treatment locations needs to be investigated. Risk of salt load returning to water resources when inappropriately controlled.	Cooling water: Ash quenching Process waters: Transport agent Utility water: Dust suppression; Fire fighting; Irrigation: Wash water rough washing (floors, rough apparatus, trucks, raw materials) Some mine re-use potential within the vicinity of AMD abstraction and treatment locations. This may accommodate 20 – 50% of the AMD on a basin by basin basis, but may not be a long-term demand as such ore resources themselves become exhausted in the short to medium term. **Conclusion** Risk of salt load returning to water resources when inappropriately controlled. Risk of increased water use infrastructure corrosion and erosion due to salt content.	Unrestricted landscape irrigation of parks, playgrounds, school yards, golf courses, cemeteries, residential, green belts. Restricted Irrigation of areas with infrequent and controlled access. Other fire protection, disaster preparedness, and construction. Domestic water uses not requiring potable water quality, *e.g.* toilet flushing. **Conclusion** Very limited potential within the vicinity of AMD abstraction and treatment locations. Risk of salt load returning to water resources, when inappropriately controlled. Risk of water use increased infrastructure corrosion and erosion due to salt content.	Food crop irrigation for crops grown for human consumption. Non-food crops and crops consumed after processing. Irrigation for fodder, fibre, flowers, seed crops, pastures, commercial nurseries and instant lawn. **Conclusion** Limited potential within the vicinity of AMD abstraction and treatment locations. Lesser risk of salt load returning to water resources, when appropriately controlled but salt load will not necessarily be removed from the system, and may accumulate in soil and groundwater systems over time. Risk of water use increased infrastructure corrosion and erosion due to salt content.

3.2 Water Users in the Witwatersrand Region

3.2.1 Background on Rand Water

Rand Water currently supplies the bulk of the industrial water to users in the Witwatersrand, and, since the start of this study, it has been suggested that it may be necessary to integrate the treated AMD into the existing Rand Water supply system.

Rand Water was established in 1903 to address the persistent water shortages experienced by the growing gold-mining industry and the cities and towns that developed as a result. In initially fulfilling this mandate, Rand Water utilised the underground water resources in the Zuurbekom and Klip River areas, but as the demand for water grew, Rand Water built the first dam on the Vaal River in 1923, the Barrage, as the dam was named. The Vaal Barrage was built together with a purification plant and pumping station at Vereeniging and a booster pumping station to the south of Johannesburg to lift water to the higher elevations of the Witwatersrand.

Since this initial investment, Rand Water’s supply infrastructure has been continually expanded to meet the growth in demand for supply in its service area. Rand Water supplies about 4 100 Mℓ/d of water to approximately 12 million people, via municipalities, mines and a small number of other direct consumers.

Rand Water buys its raw water from DWA and abstracts it from the Vaal Dam, supplied by the Lesotho Highlands scheme, and the Sterkfontein and Grootdraai Dams. It is then filtered and treated at two purification plants. The largest of these is Zuikerbosch, which includes one of the largest purification plants in the southern hemisphere.

The catchments from which Rand Water sources its raw water have an annual mean precipitation rate of 480 mm, which is approximately half of the world average and approximately equal to the South African average. The steady population growth within Rand Water's area of supply has necessitated the development of inter-basin transfer schemes to augment water supply.

Water is transferred into the Vaal Dam system through the facilities of the Upper Vaal WMA. The water is delivered in bulk from reservoirs in and around Johannesburg to Rand Water’s customers, which comprise three metropolitan councils, 15 municipalities, the Royal Bafokeng administration, 45 mines and approximately 771 industries and direct consumers.

3.2.2 Water Requirements for the Urban Sector

Rand Water's municipal customers account for almost 92% (3 767 Mℓ/d) of total demand, with mining customers adding more than 6% (246 Mℓ/d), industries only about 1% (41 Mℓ/d), and all other direct customers accounting for the balance. Future demand will be influenced by many factors, including population growth, economic growth, political priorities, climatic conditions and demand management initiatives.

Rand Water has indicated that they have received applications from industrial users for water supply. Rand Water also indicated that they currently do not have enough water to supply these industrial users and that treated AMD might be well suited to answer this demand. Besides the 41 Mℓ/d that is supplied directly to industrial users, there are also industries that are supplied via the municipal network.

The supply of AMD, whether untreated, partially treated or desalinated, to mining customers only provides an interim solution, as supply is linked to the life of the mine and thus not necessarily a Long-Term Solution (LTS).

Rand Water provides bulk potable water to more than 12 million people across Gauteng, Mpumalanga, the Free State and North West provinces, with a service delivery area stretching over 18 000 km^2, at an average of 4 100 Mℓ/d.

The continual population growth due to economic and industrial activities in the Gauteng area is the main factor driving the increase in water demand, and Rand Water is obliged to supply water to the growing number of consumers.

Rand Water's Water Demand Projection Study (Rand Water, 2009) identified an increase of 2.14% in water demand up to 2025 (refer to **Table 3.17** for projected abstraction volumes from the Vaal Dam). Rand Water has current rights to abstract 3 688 Mℓ/d of raw water from the Vaal River Government Scheme, which includes the Vaal Dam. The volume will not be adequate to supply the growth in water demand, and Rand Water is therefore applying to increase the abstraction volumes on the basis of the projected volume of raw water needed to supply consumers.

These water demand projections are for potable water supplied to customers. Rand Water's annual reports for the 2011/ 2012 financial year state that water losses (water lost as a percentage of water produced) was 4.47%, which is still above the target (< 4%) (Rand Water, 2012)

Table 3.17: Projected abstraction volumes from the Vaal Dam (2010 to 2025)

Year	2010	2015	2020	2025
Potable water (Mℓ/d)	3 843	4 318	4 769	5 172
Raw water (Mℓ/d)	3 958	4 448	4 912	5 327

3.2.3 Water Requirements for Mining and Industry

a) Bulk industrial Users

Eskom currently operates 12 coal-fired power stations, which receive water from the Integrated Vaal River System. Some of these stations were decommissioned and have now been reinstated to increase supply in response to the growing demand for electrical power to fuel the South African economy. There are also plans to develop three new power stations, envisaged to receive water from the Vaal River System. Two are scheduled to receive water from the Vaal Dam, and according to current planning, the third will be located close to the existing Kendal Power Station and will receive water from the Eastern Vaal River Sub-System (a component of the Integrated Vaal River System). The water requirement scenario that was used in the planning analysis indicated that the total water demand for all the power stations is expected to increase from 313 million m^3/a (858 Mℓ/d) in 2006 to 397 million m^3/a (1 088 Mℓ/d) in 2030.

Sasol has two plants receiving water from the Integrated Vaal River System. The primary source of water for the Sasol Synfuels facility (Secunda) was the Grootdraai Dam. With the commissioning of the Vaal River Eastern Sub-System Augmentation Project (VRESAP), water is now also abstracted from the Vaal Dam. The Sasol Synfuels facility uses approximately 230 Mℓ/d of raw water from the Vaal River system (VRESAP pipeline and/or Grootdraai Dam) as well as 25 Mℓ/d of treated water from the Rand Water supply system (thus 255 Mℓ/d in total).

The Sasol Infrachem facility (Sasolburg) uses approximately 60 Mℓ/d and is supplied from the Vaal Dam, which is supported from the Thukela-Vaal Transfer Scheme, as well as the Lesotho Highlands Water Project. The water requirements for the two Sasol facilities combined are currently more than the AMD from the Central and Eastern Basins.

A summary discussion document was received from Sasol proposing their facilities as potential industrial users of the treated AMD (refer to Annexure A). The justification for Sasol to consider the supply of treated AMD as an alternative water source is mainly that it will reduce Sasol's dependency on the stressed Vaal River system, thereby increasing security of supply.

Mittal Steel receives its water from the Vaal Dam, via Rand Water directly. In terms of their projections (reference July 2006), they were planning to decrease their current water use from 17.4 million m^3/a (47.7 Mℓ/d) in 2006 to 16.6 million m^3/a (45.5 Mℓ/d) in 2010, after which water use was projected to remain constant for the subsequent years of the planning period.

b) Private Sector Initiatives to supply treated AMD

The background information document for the Environmental Impact Assessment (EIA) for the Western Utilities Corporation Mine Water Reclamation Project (Golder, 2009) describes the establishment of environmental corporations as non-profit Section 21 companies by a number of the mines directly affected by the AMD problem. The function of these entities was given as developing and implementing a sustainable solution to the mine water issue, including the re-use of AMD in on-going mining operations where possible, and the treatment of AMD for potable use. These corporations include:

- Central Basin Environmental Corporation (CBEC):
    - Durban Roodepoort Deep (DRD) Gold Ltd;
    - East Rand Proprietary Mines (ERPM) Ltd, a wholly owned subsidiary of DRD Gold Ltd;
    - Central Rand Gold (CRG); and
    - West Wits Mining SA.
- Western Basin Environmental Corporation (WBEC):
    - Randfontein Estates Gold Mines, owned by Rand Uranium and Harmony Gold Mining Company Ltd;
    - Mogale Gold Mines, owned by Mintails; and
    - West Wits, owned by DRD Gold.
- Eastern Basin Environmental Corporation (EBEC):
    - Pamodzi Gold Limited, which operated Grootvlei Mines (Pty) Ltd; and
    - Ergo Mining (Pty) Ltd, a 50/50 venture between DRD Gold and Mintails SA.

Western Utilities Corporation (Pty) Ltd (WUC), which was contracted to develop and implement the strategy on behalf of the Western Basin Environmental Corporation (WBEC), has proceeded with an independent research and development programme. They have made submissions for the establishment of an integrated programme for the treatment of AMD from the three Witwatersrand basins. WUC (Pty) Ltd wishes to establish a project to collect mine-affected water from underground mine voids, treat the affected mine water and distribute the treated water to third parties on commercial terms.

Whilst the primary product of the proposed WUC AMD treatment plant is expected to be potable water to be distributed to Rand Water or other bulk water service providers, some of the AMD is expected to be supplied via a pipeline to Ergo Mining (Pty) Ltd (or DRD Gold and Mintails) to be used mainly for reclaiming (through mining) the gold tailings in the area.

As an alternative to the WUC centralised water treatment, DWA has proposed that some of the AMD could continue to be utilised by the operational mines in the vicinity of the individual abstraction points, for direct water use, as well as the mining and re-treatment of tailings.

Again, as with the Rand Water consideration of Hartbeespoort Dam water to be purified and pumped to mines between Madibeng and Rustenburg, and possibly to Lephalale to provide industrial consumers with industrial grade water, treated AMD could be considered as a similar source of secondary water.

As with the proposals to pipe Hartbeespoort Dam water to mines and industry, which are a considerable distance from the point of AMD abstraction, the provision of secondary pipework and pumping would be at substantial cost, and the salt load would not be reduced but transferred. End-users might not readily accept the transferred liability of handling and disposing of the salt load transferred to them in the AMD, even if partially treated.

3.2.4 Water Requirements for Irrigation

The water requirements for irrigation comprise about 35% of the total water use of the Vaal River System. The Vaalharts Irrigation Scheme, the largest in the country, uses 31% of this sector's water. Due to the extensive development in the Vaal River System and Crocodile River West WMA, which are supplied from the upper Vaal River, the local surface water resources in the Vaal WMA have been fully exploited more than three decades ago. It was therefore necessary to augment the supply by developing various schemes transferring water from the Thukela and Usutu rivers, as well as from the Kingdom of Lesotho through the Lesotho Highlands Water Project (LHWP). Any new allocations from the system will carry the full Vaal River tariff. The motivation for implementing the full cost is due to the fact that the water is very costly and only available under the condition that transfers occur from supporting systems. It will also be problematic for existing irrigators to replace river abstractions with AMD water in cases such as in the Blesbokspruit (Eastern Basin) and Klip River (Central Basin) where flows are already higher than what is needed by the Reserve.

On the other hand, the treatment and re-use of AMD for urban/industrial use reduces the effluent discharge which will have a positive effect on these rivers' habitat by improving the seasonal variability. DWA water resource managers expressed their concern that they suspected that substantial irrigation developments had taken place since 1998, most of which were perceived to be unlawful. This led to the commissioning of a water use validation study in the Upper Vaal WMA.

The assessment of the irrigation water requirements revealed that the estimated water use of this sector in 2005 was 1 060 million m^3/a (2 904 Mℓ/d). The preliminary results of the Upper Vaal WMA Validation Study (DWAF (2006c)) indicated that as much as 241 million m^3/a (660 Mℓ/d) of irrigation water used in 2005 could have been unlawful. The total registered volume of water used for irrigation in the Vaal River System was estimated to be 1 375 million m^3/a (3 767 Mℓ/d) in 2005, indicating that the increasing trend experienced since 1998 could continue further if interventions to curb unlawful water use are not successful.

4 USE OR DISCHARGE OF RAW AMD

4.1 Introduction

Due to the expected high cost of treating AMD, in terms of both CAPEX and OPEX, it was necessary also to consider the possible uses of raw AMD. This would mean that there would be absolutely no treatment, and the AMD would be supplied to consumers at the same quality that it is pumped from the mine void.

The quantity of AMD that will have to be abstracted (*i.e.* the pumping rates) from each basin, as well as the qualities of water (95th percentile) that can be expected compared to the water quality requirement for Category 4 industrial processes, are shown in **Table 4.1** and **Table 4.2** respectively. If raw AMD is supplied to users, these are the best estimates of the quantities and qualities that will be supplied. Transport of raw AMD is challenging since scaling poses a problem.

Table 4.1: Proposed Pump Rates

Basin	**Approx. Average Abstraction Rates (Mℓ/d)***	
	Average Rate	**Range**
Western	23	23 – 27
Central	46	46 – 50
Eastern	80	80

**Study Report No. 5.2 – Table 10.2*

Table 4.2: 95th percentile raw AMD qualities compared with Category 4 industrial water quality requirements

Parameter	**Unit**	**Basin[1]**			**Category 4 industrial process[2]**
		Western	**Central**	**Eastern**	
pH	@ 25°C	3.5	2.4	5.9	5 – 10
Total dissolved solids	mg/ℓ	5 434	4 592	3 358	0 – 1 600
Electrical conductivity	(mS/m) @ 25°C	442	465	363	0 – 250
Ca	mg/ℓ	703	563	421	-
Mg	mg/ℓ	-	258	166	-
Na	mg/ℓ	227	171	264	-
SO_4	mg/ℓ	3 623	3 062	2 289	0 – 500
Cl	mg/ℓ	-	146	254	0 – 500
Alkalinity as $CaCO_3$	mg/ℓ	1 520	-	560	0 – 1 200
Iron – Fe	mg/ℓ	954	108	227	0 – 10
Al	mg/ℓ	-	193	2.4	-

Parameter	**Unit**	**Basin**[1]			**Category 4 industrial process**[2]
		Western	**Central**	**Eastern**	
Mn	mg/ℓ	89	50	5.9	0 – 10

1 *Study Report No. 5.2 – Table 10.5*
2 *Target Water Quality Range as per DWAF (1996b)*

Raw AMD, or partially treated AMD (refer to **Chapter 5**), will inherently fail to be fit for use in any industry where the criteria discussed above are important. Partially treated (neutralised) AMD is primarily only suited to Category 4 industries, particularly mining or power generation operations in the transfer of tailings and ash residues to disposal sites.

The discharge of raw AMD to surface water resources is also not considered to be sustainable in the long-term because the aquatic life generally cannot survive in a low pH environment, and hence the receiving rivers may become sterile with little aquatic life. It may also render such water resources toxic for humans if significant quantities of heavy metals dissolve in the water.

As discussed in **Chapter 2.1**, dilution releases from the Vaal Dam can create enough assimilative capacity to accommodate the high salt-loading associated with AMD, but not without compromising the water supply security of the Vaal River System. In addition to the water supply security that has to be considered, the discharge of raw AMD to the environment will negatively impact on the receiving water courses, as was evident in the Western Basin where raw AMD decanted into the Tweelopies Spruit and left it sterile.

The only option for use of raw AMD that may prove to be viable is use by Mintails, or potentially by any other similar gold recovery processes, as described below. No other viable use for raw AMD has been identified.

4.2 Potential for Use by Mintails

The study team was approached by the mining reclamation company, Mintails Ltd, working with Mogale Gold which specialises in the processing and production of gold from mining tailings storage facilities. The proposal received from Mintails is briefing discussed below (for more detail, refer to DWA AMD FS 2013, Study Report No 5.4: **“Treatment Technology Options”**).

Mintails South Africa, which operates a gold recovery process in the vicinity of No. 8 Shaft in the Western Basin, has developed a process of neutralising AMD with the wastewater generated in the Tailings Water Treatment (TWT) process. This process is a very recent development, of which the study team was made aware only in September 2012. Discussions with the developers have been conducted since then to analyse the process.

As the process is a very recent development, there is not much information available other than what has been made available by the developers. There is therefore still substantial testing required to prove the efficiency and safety of the process. However, if the process can be proven to be effective as claimed, it could be a real breakthrough in the management of AMD.

With the information available to the study team, the following advantages and disadvantages could be discerned about the process:

Advantages

- The process combines two waste streams to solve the problems of both the streams;
- The volumes of waste products are substantially reduced;
- The disposal of sludge is simplified;
- The mines, which have experience in the handling and treating of cyanide, are willing to operate the process; and
- It appears that the process, if proven to be safe and acceptable, can be implemented for the next 30 years.

Disadvantages

- The process has not been fully developed to prove beyond doubt that the risk are acceptable for implementation;
- The secondary effects, such as a possible increase in heavy metals and uranium originating from the slimes, have not been researched;
- There is a possibility that the salts can be re-introduced into the water resources. If this happens the objective of the LTS may be jeopardised;
- The quality of the water does not meet the environmental or potable quality specifications, and hence further treatment is required;
- The process is dependent on the gold recovery process; and
- If no gold is produced, then the process cannot be operated, and the AMD would have to be neutralised through the HDS process. Mintails, however, has indicated that the relevant component of their gold recovery plant can easily be converted to be utilised as and HDS plant.

4.3 Conclusion

The use or disposal of raw AMD for potable purposes or to the environment is unacceptable. If this were allowed to happen, then this study, as well as the short-term intervention (STI), would altogether fail to achieve their objectives. Likewise, the parameters in raw AMD far exceed the Target Water Quality Range for domestic use, and thus the options for supplying raw AMD for potable or environmental use were not considered further. Also, since most industrial users require water that is often of higher quality than potable water, it seemed unlikely that there would be any industrial uses to consider. The Mintails process is unique in this regard, because it requires low-quality water (such as raw AMD) as input to the process.

The Mintails proposal cannot be recommended yet as a viable option for the long-term, since further engagement with Mintails is still necessary for a full evaluation of the technology. In the Mintails TWT process that is proposed for implementation in the Western Basin, raw AMD will be combined with the tailings from the gold extraction process, and the pH of the AMD will be raised in this process, thereby eliminating the need for HDS treatment. The resulting effluent from the Mintails process would still require desalination. Engagement with Mintails is on-going, particularly by the STI Team, to consider the Mintails process for neutralisation.

5 USE OR DISCHARGE OF NEUTRALISED AMD

5.1 Introduction

The options for use or discharge of neutralised AMD that have been identified, includes supply to mines, agriculture, industry and the environment. The other two options depicted in **Figure 1.1** will not be viable for neutralised AMD. The gold recovery process proposed by Mintails requires water with a low pH (*i.e.* not yet neutralised) and the quality of the neutralised AMD renders it unfit for domestic use.

The option of supplying neutralised AMD to any user is very attractive, because no further treatment would be required beyond the HDS treatment facilities of the Short-Term Intervention, on the assumption that the STI are implemented in full at the locations proposed by the TCTA Due Diligence Report (TCTA, 2011). With the expected costs, especially the OPEX, of a desalination plant being high, the prospect of eliminating that cost would greatly favour the economics of the project, if the demand for the neutralised AMD was realised.

The quality of the water expected from the HDS process proposed for the STI for the 95th percentile feed water quality (*i.e.* only 5% of samples taken had worse quality) is summarised in **Table 5.1** below.

Table 5.1: Expected product water qualities from the HDS process at the 95th percentile

Water quality parameters	Units	Basin*		
		Western	Central	Eastern
TDS	mg/ℓ	3 017	3 997	3 621
EC	µS/cm	4 826	6 395	5 794
Ca	mg/ℓ	1 055	1 020	594
Mg	mg/ℓ	18	258	166
Na	mg/ℓ	227	171	264
SO_4^{2-}	mg/ℓ	1 649	2 399	2 339
Cl	mg/ℓ	65	146	254
pH		9.5	9.5	9.5
Alkalinity	mg/ℓ as $CaCO_3$	10	10	10
Acidity	mg/ℓ as $CaCO_3$	0	0	0
Fe	mg/ℓ	< 1	< 1	< 1
Al	mg/ℓ	< 1	< 1	< 1
Mn	mg/ℓ	< 10	< 10	< 10
U	mg/ℓ	N/A	< 0.05	< 0.05

**Study Report No. 5.4: Treatment Technology Options – Table 6.1*

The restricting factor with using neutralised water wherein the salts are still present is not the users, since it has been proven (albeit only for a medium-term period) that saline water can be used for some agricultural practices and by mines for some applications. The greatest drawback of this option is that there is no certainty that the salt load would be reduced to acceptable levels and may still, either directly after re-use or indirectly if integrated into a mining process or agricultural practices and leaching over time, be discharged into the Vaal River System. If this occurs then it is only deferring and diffusing the salinity impact which is the primary issue, thereby potentially jeopardising the study goal, which is to ensure long-term water supply security and continuous fitness for use of Vaal River water by reducing the AMD-related salinity.

The investigations in this regard are discussed in the sections below.

5.2 Potential for the use of Neutralised AMD by Mines

The use of neutralised water by mines for dust suppression or irrigation on dumps has been identified as uses in the mining industry for which neutralised AMD can be applied.

Water for dust suppression does not need to be of any specific quality for the dust suppression to be effective. Likewise, there are salt-tolerant crops that can tolerate a very high salt-loading and for which neutralised AMD will be adequate, such as *Salicornia bigelovii*, which is a halophyte and can produce an average of 1.5 t/ha oil seed (equivalent to soya beans) and forage of 18.5 t/ha that remains after it is harvested.

However, the concern with respect to the two uses mention above is not whether the water quality is suited for the application to which it is applied. There is little doubt that the water quality will be acceptable for the use. The concern is for the fate of the salts in the neutralised AMD.

If used for dust suppression or irrigation, exceptional management will be required to ensure that a limited amount of the salts return to the surface or groundwater resources as run-off or through deep percolation. A major drawback of these usage options is that it essentially converts a point-source of pollution to a diffuse source, thereby making it extremely difficult, if not impossible, to manage.

5.3 Potential for the use of Neutralised AMD in Agriculture

Neutralised AMD (not desalinated) from coal mines has been used for more than 10 years under commercial farming conditions in Mpumalanga to successfully irrigate a wide range of crops as part of a WRC research project in association with Coaltech. This research proved that crops can not only be successfully irrigated with neutralised AMD, but that the soil also acts as a salt sink in that a major portion of the salts (in the form of gypsum) is precipitated within the soil and thus removed from the water environment. This is a relatively low cost option for salt removal, which provides additional benefits such as job creation and the production of agricultural products close to their markets. The option has the potential to optimise salt removal by reducing the degree of leaching that will be allowed to a level that matches the crop salinity threshold. Should a suitable geohydrological setting be used for an irrigation project, it would be necessary to intercept a large portion of the saline water draining from the soil for further treatment and removal of a further portion of the original salt load.

Irrigation with neutralised AMD will over the medium-term divert and at least temporarily store the soluble salt load within the irrigated soil (that is without even considering the immobilisation of gypsum salts as it is accepted that some salt load could be expected to be immobilised as gypsum salts within the soil matrix where AMD is irrigated). However, even though the soils can potentially provide an effective salt sink for gypsum (amongst other substances), gypsum is appreciably soluble (typically equating to a TDS of about 2 200 mg/ℓ under ambient conditions) and may in the longer term contribute to increasing salinisation of the groundwater. The leaching of these soluble salts towards surface and groundwater can at any time be reduced by terminating irrigation to a rate which will be dependent on natural rainfall. Even if the immobilisation of gypsum salts were to be discounted, irrigation with neutralised AMD can potentially provide an option to “buy time” while other options are being investigated.

The attractiveness of the irrigation option is its anticipated lower cost, while its drawbacks are that only a portion of the salt load in the treated AMD is removed and its effectiveness is not as easily checked and controlled as with a physical treatment plant. The portion of the salt load that is not removed will remain a cost to society.

Irrigation of neutralised AMD would be viable under conditions where the cost to society of dealing with the salt load emanating from irrigation is similar to that of other viable options. Under these conditions other considerations such as public preferences, job creation, perceived risk *etc.* (to the degree that their societal cost cannot be determined) will become the deciding factors. Again, it is noted that although the factors influencing the success of irrigation with neutralised AMD may appear to be rigid and restrictive, there should be the opportunity for site specific flexibility for trade-offs.

The potential to use gypsiferous mine water for crop irrigation was evaluated by du Plessis as long ago as 1983 (du Plessis, H.M., 1983) who used the steady-state chemical equilibrium model of Oster and Rhoades (1975) to predict the chemical changes and quantity of gypsum that would precipitate within a soil and the amount of salt that would leach out under different irrigation conditions. The study by du Plessis found that both the resulting soil and percolate salinity were lower compared to irrigation with chloride rich water of otherwise similar ionic composition. This was attributed to the precipitation of gypsum in soil and its subsequent removal from the aqueous environment.

Guidelines for managing irrigation with neutralised AMD have been proposed (Annandale *et al*., 2009):

- The chemical composition of the irrigation water should be well controlled and acceptable;
- the hydrological setting of the irrigated area *i.e.* position of water table, aquifers, depth of the vadose zone, fractures, *etc.* must be monitored and controlled;

- the management of any resulting leaching fraction *i.e.* pump systems, trenches, *etc.* must be attended to; and
- the fate of the draining water, *i.e.* storage and disposal thereof need to be managed.

Annandale *et al*., (2001) also used a soil water balance computer model (SWB model) to show that limited drainage and salt leaching over the long-term (50 years) is expected when irrigating with gypsiferous mine water. Field trials at Kleinkopje Colliery (Witbank, Mpumalanga, South Africa) displayed limited free percolation of water because of:

- An underlying layer of weathered sandstone with minor plinthic formations in the profile of virgin soils; and
- The spoil layer on rehabilitated land (Annandale *et al*. 2009).

According to the study (Annandale *et al*. 2009), substantial volumes of water can be used for irrigation without unacceptable build-up of salinity occurring in the soil, but do not indicate what volumes of mine water qualify as a substantial amount. With the exception of crops that are most salt sensitive, many crops can be irrigated with gypsiferous mine water. Crops such as sugar-beans, wheat, maize and potatoes have been successfully produced under such irrigation where proper land preparation and fertiliser management were done in the case of rehabilitated soil. During each study, no recognisable leaf symptoms associated with specific nutritional disorders were observed.

5.3.1 Challenges of Using Neutralised AMD for Agricultural

Practical design specifications for long-term irrigation of neutralised mine water are not currently available. The following limitations are identified to be considered:

- Annandale *et al.* (2007) concluded that whilst irrigating large areas with gypsiferous coal mine water could be a sustainable solution to AMD, large errors can be made in designing such irrigation schemes if the amount of deep drainage leaving the root zone, the storage capacity between the base of the root zone and the underlying aquifer systems, and the hydraulic characteristics of the aquifers are not properly understood and matched.
- Percolation from excess irrigation can migrate from the site, leading to rising water tables and over time, water logging and salinisation of the root zone. Failure to prevent this would require the installation of subsurface drainage systems and appropriate methods of drainage water disposal, or ultimately, lead to the failure of the irrigation scheme and potentially contaminate ground and surface water resources (Annandale *et al*., 2009). Proper irrigation management practices to prevent this are required.
- Due to the scarcity of arable and undeveloped land, mines may opt for the use of rehabilitated land which will need to be carefully managed. If irrigation with neutralised AMD is to be implemented in the Witwatersrand Basin context, the availability and suitability of land will need to be investigated properly.

- Seasonal fluctuations in soil salinity were also reported in all studies with soil salinity being maintained during the rainy summer months due to the flushing out effect of rainfall, as well as reduced irrigation whilst the converse applied for winter. If the flushing is unsuccessful, osmotic balance and recharge from groundwater will be affected.
- Irrigation water is not required at a constant rate throughout the year (or from year to year depending on the variation in rainfall and evaporation) and thus requires a balancing storage facility, since the quantity of neutralised AMD available for irrigation will have less variation than the irrigation requirements. This can realistically be provided in the mine void below the ECL, but will increase the average pumping head and require larger pumps to supply in the larger volume of water required during peak irrigation demand.
- The operation and effectiveness of the irrigation option is not as clearly visible and easy to observe as a physical treatment plant. This lack of visible effectiveness can easily give rise to scepticism over its effectiveness.

5.4 Potential for the use of Neutralised AMD in Industry

The study team did not identify any industries, within a reasonable distance (5 km – 10 km for consideration purposes) of the proposed abstraction points in any of the three basins that would be able to use the estimated quantity and quality of neutralised, saline water. If neutralised AMD were to be supplied to industries, they would have to desalinate it and need to consider this using economies of scale. There would then also be the risk that the brine would not be safely disposed of and the salts would return to the Vaal River System. Options for supplying neutralised water to industry were not investigated any further. Mining operations that could potentially use neutralised water for reprocessing schemes and tailings would be unlikely to implement safety control of the waste streams to prevent the salts returning to the Vaal River System. This option was not considered any further.

5.5 Potential for discharge to the Environment

The STI would discharge neutralised AMD into the Tweelopies Spruit of the Crocodile River West System from the Western Basin and the Elsburgspruit and Blesbokspruit of the Vaal River System from the Central and Eastern Basins respectively. The salinity model for the Crocodile River West System is currently being recalculated and updated and alternative scenarios for discharging AMD with various salinities are being evaluated. This work is carried out by WRP Consulting Engineers and the results thereof were not available by this report’s publishing date.

The TDS of the AMD is considerably higher than the resource water quality objectives (RWQOs) of the Vaal River System and is considered to be unacceptable in the long term. A high standard of desalination would be required. To meet the RWQOs of each quaternary catchment in the Vaal River System, the water must be treated to a standard similar to that of potable water.

Another option that was identified for the management of neutralised AMD is marine disposal near Durban using a redundant pipeline belonging to Transnet with a new diffuser pipe about four kilometres long into sea. It was however determined that the redundant Transnet pipeline is completely inadequate to convey the volume of neutralised AMD that is expected. A new pipeline for the full length from the Witwatersrand to the ocean will be required, which will require extensive capital and operating expenditure. The CAPEX for just the pipeline (*i.e.* other mechanical, electrical and civil works excluded) is expected to be in excess of R12 billion) and the OPEX for such a long pipeline will be exceptionally high because of friction losses. In addition, the procurement of land for a pipeline to the coast will require an extensive negotiation process which will most likely not be complete before the long-term solution needs to be implemented. This option has not been considered further.

5.6 Conclusion

The use or discharge of neutralised AMD to possible users is summarised below according to the categories of use.

5.6.1 Mines

The risk that the salts will be re-introduced into the water resources when used by mines, whether for dust suppression or irrigation on mines dumps, is too great. If a significant portion of the salts do find its way back into the water resources (especially the resources of Vaal River System) this may jeopardise the objective of the LTS. For this reason, the use of neutralised AMD by mines was not considered further in this study.

5.6.2 Agriculture

At a workshop held on 11 June 2012, it was agreed that with good management, neutralised AMD can be used for irrigation of crops, provided that the soils and crops are selected to be suited to irrigation with this type of water. Irrigation management aimed at optimising the objective of gypsum precipitation with crop production will be required.

The amount of gypsum that could be expected to precipitate within the soil need to be estimated through modelling of gypsum chemistry and plant water dynamics within a soil by simulating irrigation applications using the chemical analysis of the neutralised AMD if used for irrigation. As a first approximation it is realistic to assume that approximately 50% of the sulphates would be precipitated as gypsum in the soil. This is not expected to have adverse effects on the soils or crops in the short – to medium-term (8 years). A more exact estimate of gypsum precipitation could be predicted by a model developed by Annandale, taking into account site specific conditions. However, the balance of the salt load (*i.e.* all salts that are not precipitated as gypsum) would, with time, leach into either groundwater or surface water. The dispersed nature of irrigation makes the collection of all but small quantities of leachate impractical, so large quantities of salts could return to the river system.

Irrigation water use is very seasonal, and also varies considerably as a result of rainfall. This would require large balancing storage which can only be realistically provided in the mine void below the ECL. This would increase the average pumping head, and would require larger pumps and HDS plants to deal with the larger flows when irrigation is practised.

In the light of the information presented here, the agricultural use option is not recommend as a viable solution in the long-term, but it may be viable as a short-to medium-term measure. It is acknowledged that this option presents benefits with regards to the low cost of implementation and has tremendous potential for the management of AMD. It is therefore recommended that this option be the subject of further research where site specific studies are done, while paying specific attention to the following issues which will have to be addressed or investigated:

- Areas where such substantial volumes of AMD could be re-used have to be identified first. There is inadequate land available in the immediate vicinity of the AMD neutralisation locations to accommodate such substantial volumes on a continual basis. If land is identified, the suitability of such land will also need to be investigated.
- There needs to be an in-depth comparison between the possible use of neutralised AMD and current surface water irrigation sources that is available. Such an investigation must also consider how users would pay for the treatment and delivery of neutralised AMD to them, and it must be demonstrated that it would it be economically advantageous over the other options of water supply (surface waters or reclaimed sewage).
- The option of providing balancing storage in the mine void should be investigated in much more detail, also with regards to the increased CAPEX and OPEX that is expected due to larger pumps and greater pumping depths that will be required.
- The practical logistics of installing a piped network for irrigation use in urban areas must be considered (if suitable areas for saline irrigation are identified within urban areas).
- If the water is to be used for agricultural irrigation, the options for conveying the water to the users will have to be considered. A possible option is to use existing watercourses that are not being used anymore for normal agricultural practices. If new infrastructure is to be installed, the expectation is that the cost thereof will have to be carried by the users, *i.e.* the farmers.
- The operation and maintenance (O&M) of a separate pipeline network and pump systems must be considered. The O&M of such a system will be more complex than for a potable water distribution system, given that AMD or neutralised AMD would be highly scaling to pipelines as the gypsum precipitates out.
- The infrastructure required for delivery of the neutralised AMD to the users will require Environmental Authorisation and it must be considered who will fund, manage and implement the required EIAs.
- Strict management on the use and control of the water to ensure that the users of neutralised AMD comply with guidelines / regulations that must still be put in place.

- A monitoring programme will be required to keep track of the performance of irrigation use and to ensure that the Vaal River System is not compromised. It must also be established to what extent a user can be held liable if the salt load that is returned to the water system (surface and ground water) exceeds the specified limit.
- Before implementation on a scale that is required for the AMD generated in the Witwatersrand mining basins, there needs to be further research to demonstrate that the neutralised AMD is suitable for specific land and crops as an alternative to current water sources. Funding for such research must be sourced.
- The illegal water users in the area that are rightfully being taken to task and their irrigation operations being shut down could be potential users of neutralised AMD. However, this option will be hampered by the decision taken by DWA that any new allocations will carry the full Vaal River Tariff (**Chapter 3.2.4**).
- Options that are available for the treatment of leachate that is collected by surface and subsurface drainage systems will have to be considered.
- In the event that irrigation is implemented as a solution, but after a period proves to be unsuitable for the long-term, it must be determined who holds the responsibility for the infrastructure that's been installed.
- Claims that the AMD has damaged the soil productivity, or crop productivity, *etc.* may occur. It must be determined how these claims will be adjudicated and compensated. Alternatively, farmers should undertake to hold no one liable for crop losses or damages to soils.

5.6.3 Industrial Water Use

The study team did not identify any industries, within reasonable distance (5–10 km for consideration purposes) of the proposed abstraction points in any of the basins that would be able to use the estimated quantity and quality of neutralised but saline water. It is, however, likely that some industries would be supplied with desalinated water by Rand Water, as discussed in **Chapter 6** of this report.

5.6.4 Environment

The discharge of neutralised, but saline AMD to the environment, either into river systems or to the ocean is not considered viable. The environmental (river systems) and economical (marine disposal) considerations have ruled out these options and it is not considered further in this study. However, it is recommended that during implementation the option of discharging neutralised AMD to the Crocodile (West) River in the Western Basin should be considered. This will be dependent on the outcome of the salinity modelling for the Crocodile (West) River System that is carried out by WRP Consulting Engineers, but based on the information currently available this option could not be recommended as part of this Feasibility Study.

6 USE OR DISCHARGE OF DESALINATED WATER

The options for the use or discharge of desalinated water can be classified into the following categories: potable, industrial / mining, agricultural and environmental discharge. The standards for treatment are covered in DWA AMD FS 2013, Study Report No. 5.4: **"Treatment Technology Options"**.

6.1 Domestic Use

With water becoming a threatened resource and the availability of potable water becoming scarce, using the desalinated water for potable use appeared to be an alternative option and needed to be critically assessed.

The key stakeholders that could play a role would be Rand Water, Johannesburg Water, Magalies Water, Ekurhuleni and other municipalities. Rand Water is regarded as the primary stakeholder and supplies secondary users such as Johannesburg Water, Magalies Water, Ekurhuleni and other municipalities. Recommendations in this regard (*e.g.* institutional arrangements, funding, *etc.*) will be made in DWA AMD FS 2013, Study Report No. 7: **"Institutional, Procurement and Financing Options**", and DWA AMD FS 2013, Study Report No. 8: **"Implementation Strategy and Action Plan"**.

6.1.1 Rand Water

The sites of the AMD treatment facilities all fall within the Rand Water area of supply and jurisdiction. Rand Water is therefore considered to be the primary potential distributor and stakeholder.

Discussions with Rand Water have been initiated with respect to where the water could be delivered to their system as well as the required quality and quantity of water that could be accommodated.

Rand Water currently supplies 4 100 Mℓ/d to their consumers, serving about 12 million people. AMD could only supply 149 Mℓ/d, which is less than 5% of the total requirement. Rand Water is concerned about the perceived reputational risk associated with treated AMD, especially since it is such a small volume in comparison with their total supply volume.

In discussions with Rand Water, they confirmed that they are not in favour of supplying treated AMD as potable water to domestic users. Rand Water was concerned about perceptions of their clients/end-users that they would be drinking 'radioactive water'. Concerns were raised that treated AMD water does not have a proven track record to ensure that the radioactivity is adequately removed from the water. Rand Water was of the opinion that the research carried out on the quality of treated AMD does not provide conclusive evidence that the radioactivity has been removed below the required threshold. They were also averse to blending treated AMD water into their systems. Another argument to support their decision was that industrial grade water could be sold at a higher unit price than potable water.

Furthermore, Rand Water did not necessarily agree with the positions of the treatment sites. They were of the opinion that some of their end-users, such as Ekurhuleni Metropolitan Municipality, would be better suited to utilise the treated water. They were, however, prepared to discuss possible uses and the infrastructure required to supply industrial users.

Rand Water was also prepared to consider the idea of supplying or supplementing industrial grade water to mines from treated AMD water, especially from the Western Basin, from which the mines in the Rustenburg area could benefit. These possibilities will have to be considered with Rand Water on a case-by-case basis during implementation. This would have the advantage that the treated AMD would replace water which would otherwise be supplied from the Vaal River System. A list of Rand Water's main recipients of water, based on those users' historic monthly accounts, is included as **Appendix A**. These users could be considered in future negotiations to confirm a suitable end-user of the treated AMD.

It is cautioned, however, that given the sensitivity surrounding the introduction of treated AMD into domestic water supply systems, it would be necessary to ensure that the treated AMD complies fully with the highest quality specified in terms of the South African National Standards – SANS 241 Drinking Water Standards, *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996a) and Rand Water requirements. The SANS 241 limits (Acute Health and Aesthetic) are shown in **Table 6.1** below against the water qualities that Rand Water supplied to the Johannesburg Metropolitan Municipality in the past.

Table 6.1: SANS 241 Comparison against Rand Water's supply

	Chlorides (mg/ℓ)	**Sulphates (mg/ℓ**	**TDS (mg/ℓ)**
SANS 241 : Acute Health[1]	-	500	-
Aesthetic[2]	300	250	1 200
Rand Water[3]	9 – 13	13 – 17	130 – 230
Vaal Dam at Rand Water intake[4, 5]			
1/10/2012 – 31/12/2012	< 10	21	208
1/01/2013 – 31/03/2013	< 10	24	143
1/04/2013 – 30/06/2013	< 10	22	137
1/07/2013 – 30/09/2013	< 10	21	130

1 *Poses an immediate unacceptable health risk if consumed*
2 *Taints water with respect to taste, odour and colour and that does not pose an unacceptable health risk*
3 *From Rand Water website for period 22 June to 22 July 2011 (Average ± 3 standard deviations). Water supplied to Johannesburg Metropolitan Municipality. Assumes that industrial customers are supplied via the same network.*
4 *http://www.reservoir.co.za/forums/vaaldam/vaaldam_forum/vaaldam_chemical_2013/RW_vaaldam_jul-sep2013.pdf*
5 *TDS values calculated from Conductivity using a conversion factor of 6.5 to convert from mS/m to mg/ℓ.*

In terms of salinity, TDS and sulphate concentrations will need to be better than the SANS 241 requirement to be comparable with Rand Water quality water and to suitably address salt-loading to be caused by the underground mine water, and may therefore have to equate to the Vaal Dam quality. A TDS concentration of 200 mg/ℓ was used in the modelling runs for the preferred scenario which excluded salt-loading from underground mine water.

It was noted that the AMD released into the surface water resources, particularly those draining into the Vaal River water supply system, would indirectly become integrated into the potable water supply, but without the emotion and public sensitivity that might arise from direct distribution of treated AMD within the potable water supply system.

It was also noted that the potential exists to treat AMD to a lower water quality, for blending with better quality water, if it can be demonstrated that it would be acceptable to users. Whilst the SANS Drinking Water Standards and *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996a) are used as the default, the treatment technology does not necessarily need to achieve these quality standards in itself, unless that water is to be sold directly as drinking water or bottled water.

As in the case of the eMalahleni AMD treatment plant, whilst the technology can achieve drinking water quality or any lower standard, it does not necessarily need to achieve such stringent limits if there is dilution or assimilative capacity in the bulk water system into which treated AMD would be introduced.

This does require that the current bulk water supply quality standards, as well as the projected future water quality and quantity for the various water systems into which the treated AMD could potentially be introduced, must be compared against the SANS Drinking Water Quality Standards and *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996a). It is also necessary to establish how much assimilative capacity is available for the various components of the treated AMD in order to determine what the LTS treatment technology must achieve.

6.1.2 Magalies Water

Magalies Water is a parastatal institution that provides potable water to areas within four provinces, namely Gauteng, Limpopo, North West and Mpumalanga. The most viable solution for AMD involving Magalies Water would be to supply treated water from the Western Basin. Treated water pipelines from the treatment works could be linked with their existing reservoirs for inclusion in their integrated system.

A quality control protocol would be required to ensure that sustainable quality water is delivered to Magalies Water.

In addition to the required water quality, complying with SANS 241 Drinking Water Standards (Acute Health or Aesthetic), the following would also need to be considered:

- Quantity requirements;
- Available infrastructure;
- Required infrastructure;

- Concerns/perceptions; and
- Value adding/benefits or negative/positive impacts.

Magalies Water has not been engaged in the Feasibility Study.

6.1.3 Johannesburg Water

The following would need to be considered:

- Locations: They could probably only use water from individual basins;
- Quality requirements (SANS 241, Acute Health or Aesthetic – Salinity similar to Vaal Dam quality);
- Quantity requirements;
- Available infrastructure;
- Required infrastructure;
- Concerns/perceptions; and
- Value adding/benefits or negative/positive impacts.

Johannesburg Water has not been engaged in the Feasibility Study, except for their involvement as members of the SSC and attendance of the Focus Group meeting with Affected Municipalities.

6.1.4 Ekurhuleni Metropolitan Municipality

The following would need to be considered:

- Locations: They could probably only use water from individual basins;
- Quality requirements (SANS 241, Acute Health or Aesthetic – Salinity similar to Vaal Dam quality);
- Quantity requirements;
- Available infrastructure;
- Required infrastructure;
- Concerns/perceptions; and
- Value adding/benefits or negative/positive impacts.

Ekurhuleni Metropolitan Municipality has not been engaged in the Feasibility Study, except for their involvement as members of the SSC.

6.1.5 Other potential potable water users

The following would need to be considered:

- Locations: Water boards could probably only use water from their individual basins, if available, and such use would be basin specific. Consideration would have to be given to the clients they serve.

- Quality requirements (SANS 241, Acute Health or Aesthetic – Salinity similar to Vaal Dam quality);
- Quantity requirements;
- Available infrastructure;
- Required infrastructure;
- Concerns/perceptions; and
- Value adding/benefits or negative/positive impacts.

No other potential potable water users (apart from Rand Water) have been engaged in the Feasibility Study.

6.1.6 Examples of Urban Applications

Examples of urban applications include:

- Unrestricted landscape, irrigation of parks, playgrounds, school yards and golf courses;
- Irrigation of cemeteries, residential and green belts;
- Restricted irrigation of areas with infrequent and controlled access; and
- Other, such as fire fighting, disaster preparedness and construction.

The urban irrigation uses mentioned above is discussed in **Chapter 3.1.3**.

6.2 Mining and Industrial Use

Rand Water is of the opinion that water treated to potable water standards could be provided to their industrial users through ‘isolated’ systems, which would help avoid the risk of negative public perceptions. This was discussed at the meetings with Rand Water on 27 August 2012, 3 September 2012 and 11 October 2012.

The information in the following sections was obtained from Rand Water.

6.2.1 Location of potential users

The demand for industrial grade water that was identified in the Eastern Basin was from the Secunda (Sasol Synfuels facility) and ERPM demand areas.

Potential demand in the Central Basin was identified for use in the re-mining of existing mine dumps in the area as well as use by the Sasol Infrachem facility in Sasolburg.

The potential demand in the Western Basin was identified for use in the mining activities in the Westonaria and Merafong municipalities.

6.2.2 Volume and Quality Required

Table 6.2 shows the water qualities required by Sasol and Rand Water and **Table 6.3** shows the potential demand as well as the potential use of water in each basin, as indicated by Rand Water.

Table 6.2: Quality of water required by industrial customers

	Chlorides (mg/l)	**Sulphates (mg/l)**	**TDS (mg/l)**
Rand Water[1]	9 – 13	13 – 17	130 – 230
Sasol: Cooling water – current Cooling water - preferred Boiler Feed Water			150 40 0.1 – 1

1 From Rand Water website for period 22 June to 22 July 2011 (Average ± 3 standard deviations). Water supplied to Johannesburg Metropolitan Municipality. Assumes that industrial customers are supplied via the same network.

Table 6.3: Potential demand and use of water in each basin

AMD Area	Purpose	Average daily consumption Mℓ/d	Peak summer demand Mℓ/d	Potential industrial grade Mℓ/d (ADD[1])	Potential industrial grade Mℓ/d (PSD[2])	Plant hydraulic capacity Mℓ/d	Acid mine water available Mℓ/d
Eastern Basin 1B (Secunda)	Process water, cooling, dust suppression	36.00	54.00	80.50	120.75	120.75	110.00
Eastern Basin 1A (Nigel/Boksburg)	Process water, cooling, dust suppression	8.00	12.00	7.20	10.80	10.80	
Central Basin	Process water, cooling, dust suppression, recovery of mine dumps	16.16	24.23	12.12	18.18	18.18	60.00
Western Basin	Process water, cooling, dust suppression	59.67	89.51	47.74	71.61	71.61	35.00

1: Average Daily Demand
2: Peak Service Demand

6.2.3 Point of connection to Rand Water infrastructure

Rand Water indicated that new dedicated infrastructure would be required for potential users of AMD treated water to avoid mixing that water with conventional potable water.

6.2.4 Recommendations

The supply of desalinated AMD to industrial users is recommended for further investigation during the Feasibility Phase. This option poses the minimum risk with regards to the environment and society, while still generating an income from the sale of treated water.

The information presented in this section is what was made available by Rand Water to the study team. The Department will have to engage Rand Water in discussion during the implementation phase to come to agreements stipulating the details of possible supply of desalinated AMD to Rand Water (*e.g.* locations, qualities, quantities, price, *etc.*).

6.3 Agricultural Use

Desalinated water from AMD is expected to be substantially more expensive to abstract, transport, treat and distribute to users than other possible alternatives (*e.g.* water from the Vaal Dam). One of the objectives of the Feasibility Study is to identify a solution that is economically self-sustaining as far as possible.

Providing desalinated AMD water for agriculture would probably require subsidies from government or other parties and would ultimately place a burden on taxpayers. Desalinated AMD water has not been considered viable for agricultural use; only neutralised AMD water was considered for agricultural use, as discussed in **Chapter 5**.

6.4 Environmental Use

6.4.1 Discharge Scenarios

a) Western Basin

The Tweelopies Spruit used to be a non-perennial stream prior to the uncontrolled decant of untreated AMD started in 2002. There are no sensitive wetlands in this river; however, the Tweelopies Spruit does flow through the Krugersdorp Game Reserve, which can be regarded as a sensitive environment. The RWQOs that are applicable in this basin are stricter than the requirements for livestock watering. The quality of discharged water would therefore not pose a problem provided that the discharge of such water would not cause the water quality in the Tweelopies Spruit to deteriorate to a quality worse than the set RWQOs. Alternatively, the water could be piped and discharged into the Bloubank Spruit, where the Percy Steward Wastewater Treatment Works is already discharging, resulting in the Bloubank Spruit no longer being a non-perennial river. The impacts would be very similar in both rivers, but a possible benefit could be that at least the Tweelopies Spruit might return to normal conditions.

The discharge scenarios for the Western Basin are summarised in **Table 6.4**.

Table 6.4: Discharge scenarios for the Western Basin

Scenario	Impact on receiving water quality	Impact on stream flow quantity (habitat and biota)	Comments
1. Desalinated water discharged into the Tweelopies Spruit.	Limited impact provided that water is treated to a level that will not negatively impact on the RWQOs.	Continuous flow in the Tweelopies Spruit will impact on biota and habitat. Potential displacement of sediments.	None.
2. Desalinated water discharged into the Bloubank Spruit.	Limited impact provided that water is treated to a level that will not negatively impact on the RWQOs.	Limited additional impact on stream flow of Rietspruit, which is already regarded as environmentally sensitive and important.	Percy Steward Wastewater Treatment Works is discharging into the Bloubank Spruit and already resulting in constant continuous flow.

b) Central Basin

Consideration of the wetland in the Klip River and the water quality to be discharged are the environmental drivers that would determine the discharge point for the desalinated AMD from the Central Basin. The discharge point below the wetland could be either in the Elsburgspruit (which falls within the Klip River quaternary) or in the Klip River after the confluence with the Rietspruit into which the Elsburgspruit drains. If discharged above the wetland, the Klipspruit, which falls in the upper catchment of the Klip River, would be the selected discharge point. The exact points for discharge should be selected on the basis of cost once the user requirements and the needs of sensitive wetland areas have been satisfied.

The RWQOs for the Klip River have been set at the 'acceptable' level. These RWQOs were determined with input from users in the catchment, and the water quality requirements are likely to become stricter in the future.

A summary of discharge scenarios for the Central Basin is shown in **Table 6.5**.

Table 6.5: Scenarios for discharge to the water resource in the Central Basin

Scenario	Impact on receiving water quality	Impact on stream flow quantity (habitat and biota)	Comments
1. Discharge of desalinated AMD into Klipspruit above wetland.	Limited.	Increased channelling and further impact on wetland functioning.	Treated water needs to be of appropriate quality so as not to impact on the set RWQOs. There is a need to ensure that illegal use downstream does not increase.
2. Discharge of desalinated AMD below wetland in Elsburg Spruit or any other stream within the Klip River catchment. (via Elsburgspruit, then entering the Klip River at its confluence with the Rietspruit).	Limited.	Limited.	Treated water needs to be of appropriate quality so as not to impact on the set RWQOs. There is a need to ensure that illegal use downstream does not increase.

c) Eastern Basin

The factors governing the discharge of desalinated water into the environment in this basin include the sensitive wetland of the Blesbokspruit in the Eastern Basin and the quality of the water to be discharged.

Another consideration is whether the Blesbokspruit Ramsar Wetland is underlain by dolomites, which might lead to ingress of the treated water into the mine void through the dolomites. The location of the dolomites is shown in **Figure 6.1**. There is also shallower coal mining (Largo Colliery) that can act as "conduit" of surface water to dolomites. The Blesbokspruit is already in a severely deteriorated state. The RWQOs were set at the level for managing the water quality to an 'acceptable' level, while the present ecological state of the river is Category E (unacceptable). Apart from an improvement in the habitat and biota, a substantial improvement of the water quality of the artificial discharge (*i.e.* treated AMD) of water would therefore have to be achieved for the water quality to become acceptable. The discharge of water at the right quality and of the right quantity would therefore have to be modelled to mimic natural flow as far as possible.

If the water being discharged would not cause the water quality in the Tweelopies Spruit to deteriorate to a quality worse than the set RWQOs, there will be no further impacts on recreational or livestock watering users.

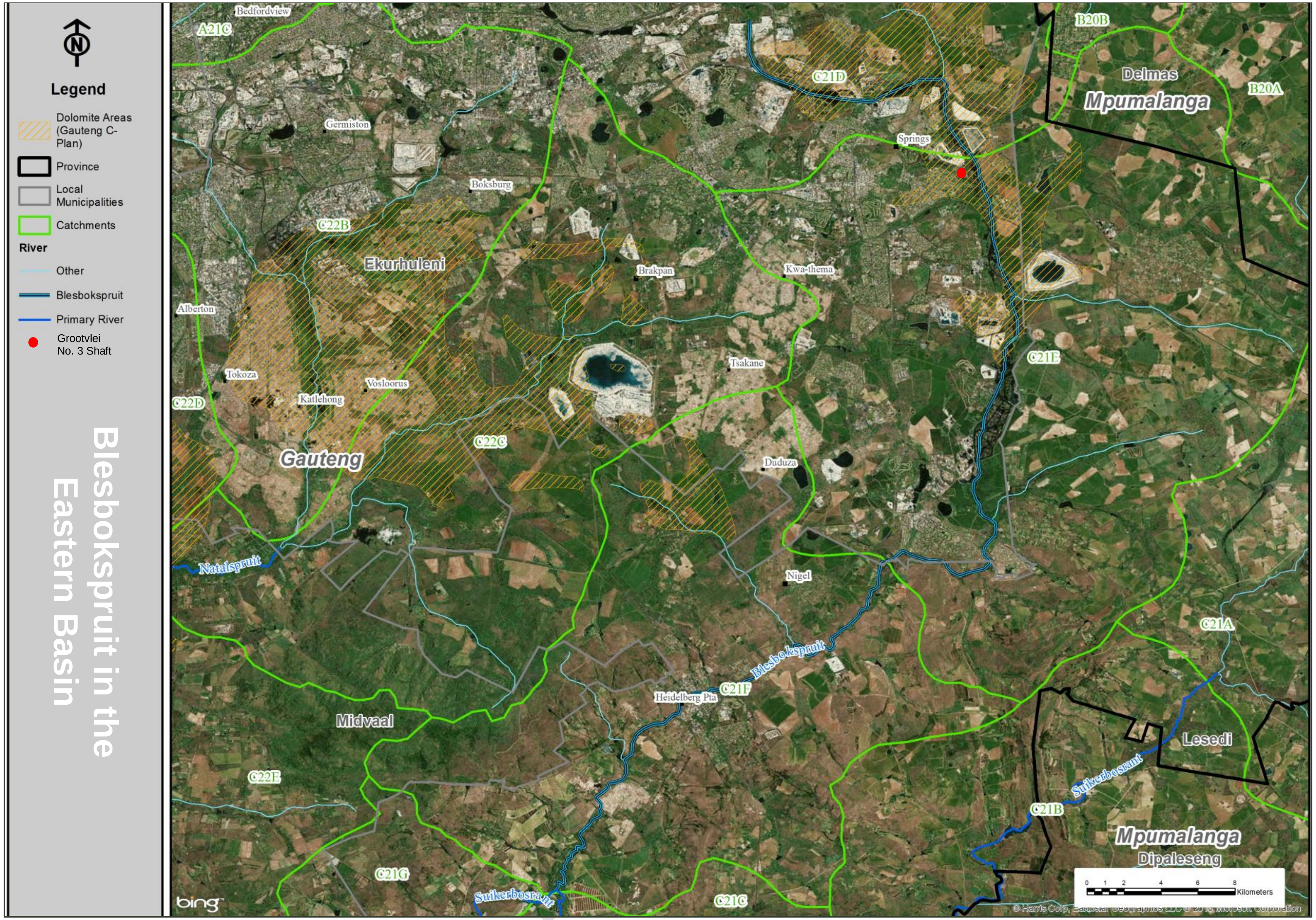

Figure 6.1: Location of dolomites in the Blesbokspruit

The discharge scenarios are summarised in **Table 6.6**.

Table 6.6: Scenarios for discharge to the water resource in the Eastern Basin

Scenario	Impact on receiving water quality	Impact on stream flow quantity (habitat and biota)	Comments
1. Discharge of desalinated AMD into Blesbokspruit above wetland.	Limited impact if water quality will not cause the RWQOs to be violated.	Constant flow through the wetlands impacts on natural function of the wetland.	Flow can be artificially regulated by possibly making use of existing or new upstream impoundments. Water quality after desalinations should not cause the current RWQOs set for the Blesbokspruit to be violated.
2. Discharge of desalinated AMD below wetland in Blesbokspruit.	Limited impact if water quality will not cause the RWQOs to be violated.	Limited impact.	Water becomes available for use. There is a need to ensure that additional water is available for use by Rand Water and that illegal use does not take place downstream of the discharge point.

6.4.2 Recommendations

The discussion in this report did not include any economic analyses of the discharge of desalinated AMD to the environment. However, given the expected high costs (CAPEX and OPEX) of neutralising and desalinating AMD, and the very limited number of opportunities for cost recovery if discharged to the environment, this option is not considered economically viable and is therefore not recommended for the long term. It might be necessary to discharge the treated AMD to the environment for short periods of time for a variety of reasons (*e.g.* system failure, excessive ingress, *etc.*). This would be acceptable as long as the water quality to be discharged does not cause the set RWQOs as listed above for each quaternary catchment to be violated.

The following potential discharge options are recommended in the event that desalinated AMD is to be discharged into the streams.

a) Western Basin

Rerouting of treated AMD - Treated AMD could be rerouted to the Percy Steward Wastewater Treatment Works to be discharged with the treated wastewater at a less sensitive point in the Bloubank Spruit.

b) Central Basin

Treated water be discharged downstream of the wetland in the Elsburg Spruit - Water would be treated to a level that is acceptable for discharge below the wetland and would not cause the RWQOs to be violated.

c) Eastern Basin

Discharge of treated water downstream of the Marievale Bird Sanctuary - The Marievale Bird Sanctuary is situated within the Blesbokspruit Ramsar site. This sanctuary extends over 1 000 ha of land, hosting the largest variety of bird species in Gauteng province. Water must be treated to a quality that would not cause the RWQOs set for the Suikerbosrant River to be violated.

Exchange of current abstraction for treated AMD water - Irrigation is taking place downstream of the proposed discharge point. More information is needed on the possible option of exchanging treated water for water currently being abstracted from other surface sources in the Vaal River System.

7 CONCLUSIONS AND WAY FORWARD

This report discussed the various options for use or discharge of AMD that has been treated to certain qualities, *i.e.* raw AMD, neutralised AMD and fully treated AMD (neutralised and desalinated). The options that were considered are:

Table 7.1: Summary of options considered

	Option	Comment and Recommendations
Raw AMD	Use by Mintails	Not recommended as a viable long-term solution. Further investigations and discussions with Mintails required before possible implementation in the medium-term can be considered.
Neutralised AMD	Domestic non-potable (toilets, parks, gardens, *etc.*)	Separate reticulation for small quantities is not affordable. Salt-loading due to return flows, from groundwater recharge, *etc.* poses an unacceptable risk to water security in the Vaal River System. It is therefore not viable.
	Industrial	No industries identified that can accommodate water of such quality. Therefore, not viable.
	Agricultural Irrigation	Uncertainty about land suitability, destination of salts, problems of seasonal demand variation and long-term effects. Further research, which can be conducted as short-to medium term measure for the AMD problem, is necessary to investigate these challenges (refer to **Chapter 5.6.2**).
	River release (environmental)	Discharge of neutralised AMD to the environment poses a significant risk that the RWQOs of the receiving river systems will be violated. However, in the short-to-medium-term, the Crocodile (West) River has assimilative capacity to accommodate neutralised AMD, and the impact on broader systems is also acceptable in the short-to-medium-term, although discharge of such water will require environmental authorisation.
	Marine Disposal	Capital investment and operating expenditure too high. Procurement of land will also not fit into the timeframe required for implementation and there will be no income to offset the costs.
Fully treated AMD (neutralised and desalinated)	Domestic	The reservations of Rand Water and the possible negative public perception resulted in supply for domestic use not being recommended as the preferred option.
	Industrial	This is the **Preferred Option,** but further discussions with Rand Water are required. Such discussions will be between DWA and Rand Water and form part of the implementation. Several local industries exist in the vicinity of the three mining basins, which each uses small quantities of water. However, it will be more feasible to supply remote bulk users that have been identified (*e.g.* Eskom, Sasol, Mittal Steel, *etc.*)
	Agricultural Irrigation	Not financially sustainable.
	River release (environmental)	Acceptable only downstream of wetlands in Blesbokspruit and Klipspruit (and acceptable in Elsburgspruit if RWQOs are met), but not economically viable.

The water qualities required by Rand Water, Sasol and the environment compared against the SANS 241 limits (Acute Health and Aesthetic) are summarised in **Table 5.2**:

Table 5.2: Summary of required water qualities

	Chlorides (mg/l)	**Sulphates (mg/l)**	**TDS (mg/l)**
SANS 241 : Acute Health[1]	-	500	-
Aesthetic[2]	300	250	1 200
Environment RWQO:			
Western Basin (Tweelopies Spruit)	75	400	481
Central Basin (Klip River) (Low/high)	50/75	200/350	520/650
Eastern Basin (Blesbokspruit) (Low/high)	80/150	150/300	293/455
Rand Water[3]	9 – 13	13 – 17	130 – 230
Vaal Dam at Rand Water intake[4, 5]			
1/10/2012 – 31/12/2012	< 10	21	208
1/01/2013 – 31/03/2013	< 10	24	143
1/04/2013 – 30/06/2013	< 10	22	137
1/07/2013 – 30/09/2013	< 10	21	130
Sasol: Cooling water – current			150
Cooling water - preferred			40
Boiler Feed Water			0.1 – 1

[1] *Poses an immediate unacceptable health risk if consumed*
[2] *Taints water with respect to taste, odour and colour and that does not pose an unacceptable health risk*
[3] *From Rand Water website for period 22 June to 22 July 2011 (Average ± 3 standard deviations). Water supplied to Johannesburg Metropolitan Municipality. Assumes that industrial customers are supplied via the same network.*
[4] *http://www.reservoir.co.za/forums/vaaldam/vaaldam_forum/vaaldam_chemical_2013/RW_vaaldam_jul-sep2013.pdf*
[5] *TDS values calculated from Conductivity using a conversion factor of 6.5 to convert from mS/m to mg/ℓ.*

Alternative treatment processes are described in DWA AMD FS 2013, Study Report No. 5.4: **"Treatment Technology Options"** and alternatives for the management of waste or residues are described in DWA AMD FS 2013, Study Report No. 5.5: **"Options for the Sustainable Management and Use of Residue Products from the Treatment of AMD"**. The selection of a treatment process is made in DWA AMD FS 2013, Study Report No. 5: **"Technical Prefeasibility Report"**, together with the selection of an abstraction site, water use and discharge options, as well as waste management options. The Technical Prefeasibility Report assesses combinations of options and waste/residue management. The most attractive combinations of options are selected for preliminary cost estimation, and the most feasible option for each basin is recommended as the Reference Project for further investigation in the Concept Design of the Feasibility Phase (DWA AMD FS 2013, Study Report No. 6: **"Concept Design"**, DWA AMD FS 2013, Study Report No. 6.1: **"Concept Design: Drawings"** and DWA AMD FS 2013, Study Report No. 6.2: **"Concept Design: Costing"**).

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Annexure A
Sasol as potential user of treated AMD

sasol
reaching new frontiers

Sasol as potential user of treated Acid Mine Drainage

Summary discussion document

16 May 2013

1 Introduction

Sasol has expressed interest in the potential use of treated Acid Mine Drainage (AMD) from the Gauteng basins and has been engaging with the Department of Water Affairs (DWA) and the appointed DWA Consultant team for the AMD Long-Term Feasibility Study in this regard.

The objective of the engagement is to establish the technical and financial feasibility of the opportunity to supply treated AMD to the Sasol operating facilities in Sasolburg and/or Secunda. The treated AMD would replace raw water supply from the Vaal River system and would be utilised for industrial purposes (i.e. mainly steam production and cooling).

This discussion document provides a summary of Sasol's position on various aspects of the opportunity to use treated AMD for industrial purposes at Sasol's operating facilities and is intended to provide an input into the AMD Long-Term Feasibility Study report as well as subsequent discussions.

2 Locations for use

The two locations considered for use of treated AMD are as follows:

a. Sasol Infrachem, Sasolburg
The Sasol Infrachem complex consists of a number of chemical manufacturing and refining operations and is located in Sasolburg, approximately 60km south of Gold Reef City, Johannesburg (Central AMD basin).

b. Sasol Synfuels, Secunda
The Sasol Synfuels complex consists of fuels and chemical manufacturing operations and is located in Secunda, approximately 80km east of Springs on the East Rand (Eastern AMD basin).

3 Volumes of treated AMD required

The volumes of treated AMD that could be utilised at the two Sasol facilities respectively are as follows:

a. Sasol Infrachem, Sasolburg

The Sasol Infrachem facility use approximately 60 Ml/d of raw water from the Vaal River and could therefore potentially utilise the estimated **50 Ml/d** of treated AMD projected from the Central Basin.

b. Sasol Synfuels, Secunda

The Sasol Synfuels facility use approximately 230 Ml/d of raw water from the Vaal River system (VRESAP pipeline and/or Grootdraai Dam) as well as 25 Ml/d of treated water from the Rand Water supply system (255 Ml/d in total) and could therefore potentially utilise the estimated **90 Ml/d** of treated AMD projected from the Eastern Basin.

4 Quality of treated AMD required

The treated AMD would be utilised to replace existing raw water supplied from the Vaal River system and would be treated further to demineralised "boiler feed" water quality for steam production as well as cooling water make-up water. The major water quality parameters of concern to the Sasol processes would be Total Dissolved Salts (TDS), Total Suspended Solids (TSS) and Total Organic Carbon (TOC).

The departure point for Sasol is that the treated AMD would have to be of **equal or better quality than existing Vaal River raw water** (in terms of TDS) to be considered as a feasible alternative. Water of poorer quality (higher TDS) would not be beneficial and could not be utilised in the Sasol processes without further exacerbating the existing salt handling costs at the respective sites. Water of better quality than existing Vaal River raw water (TDS, TSS and TOC) would have additional benefits in terms of reduced water treatment and salt handling costs.

The notion that treated AMD for "industrial use"" could be of poorer quality than water required for potable use is not correct in the case of supply of treated AMD to Sasol.

For the purpose of the AMD Long-Term Feasibility Study it is assumed that some configuration of Reverse Osmosis (RO) membrane process would be used to desalinate the AMD, producing treated water of very low TSS and TOC content (<1 mg/l each) and varying concentrations of TDS, depending on the treatment process configuration. Two possible qualities of treated AMD have been assumed for potential supply to Sasol:

a. Potable equivalent quality ("base case")

Water quality roughly equivalent to Rand Water (Vaal River) potable supply:

TSS <1 mg/l (as a result of RO process)
TOC <1 mg/l (as a result of RO process)
TDS approximately **150 mg/l**

b. High quality ("value added case")

Water with substantially lower TDS concentration than existing Rand Water (Vaal River) potable or raw water supply:

TSS <1 mg/l (as a result of RO process)
TOC <1 mg/l (as a result of RO process)
TDS approximately **40 mg/l**

5 Supply period

The expected lifetime of the Sasol Infrachem (Sasolburg) and Sasol Synfuels (Secunda) facilities are estimated to be at least until 2030, with studies on-going to extend the lifetime of both these facilities.

Should it be found to be feasible, an estimated supply period of treated AMD of **at least 15 years** (2015 – 2030) can be assumed for Sasol Infrachem (Sasolburg) and Sasol Synfuels (Secunda), with further extension of supply periods being possible.

6 Impact on VRESAP pipeline

The Vaal River Eastern Sub-system Augmentation Project (VRESAP) pipeline has been in operation since 2008 and is supplying water from the Vaal Dam to Sasol Synfuels in Secunda and the Eskom power stations in the Mpumalanga Highveld area. Sasol has a share of approximately 40% of the pipeline and is repaying their part of the loans to the TCTA through an additional tariff levied on the total raw water supplied from the Vaal River system (via the VRESAP pipeline or the Grootdraai Dam). The VRESAP tariff is linked to off-take volumes, with the tariffs increasing with decreasing off-take volumes in order to service the loans in the agreed 20-year repayment period (2008 – 2028) on a “take-or-pay” principle.

The existing supply of approximately 230 Ml/d to Sasol Synfuels from the Vaal River system will decrease by approximately 90 Ml/d, should treated AMD be replacing a portion of the raw water requirements of Sasol Synfuels. This will result in an increase in the VRESAP tariff in order to repay Sasol’s share of the VRESAP pipeline by 2028. The financial impact on Sasol should be neutral, but the increased VRESAP tariff will have to be taken into account in the determination of a feasible tariff for treated AMD.

The supply of treated AMD to Sasol Synfuels will result in redundant capacity of 90 Ml/d on the VRESAP pipeline which will become available to new users along the pipeline route.

7 Tariff and financial feasibility considerations

As with the base case water quality, the departure point for Sasol is that treated AMD should be supplied at **equal or lower cost, compared to existing raw water supply**, for it to be a financially feasible alternative for Sasol to consider. The comparative cost of treated AMD should include the capital and operating cost of new pipelines required to transport the AMD from the treatment plant/s to the final point of consumption (i.e. total “landed cost”).

Calculation of final feasible tariffs for treated AMD is still subject to detailed financial and economic modeling and is beyond the scope of this discussion document.

8 Conclusion

The justification for Sasol to consider the supply of treated AMD as an alternative water source is mainly that it will reduce Sasol's dependency on the stressed Vaal River system, thereby increasing security of supply. The supply of treated AMD has a higher risk than conventional raw water supply as a result of the complicated AMD treatment technologies involved. This additional risk will have to be weighed against the potential cost, water quality and water security benefits.

Sasol is aware that the total cost for the treatment of AMD (capital, operating and brine handling) will exceed the maximum tariff that could feasibly be recovered from any end-user (be that potable or industrial use). The balance of the treatment cost of AMD will have to be provided from an alternative funding source, still to be determined by Government (e.g. National Treasury, a levy on all Vaal system users, recovery from mining sector or a combination of such measures).

In our view, the supply of treated AMD to Sasol facilities in Sasolburg and/or Secunda will provide DWA with a **reliable, long-term user** which is **financially sound** and from which a substantial portion **of the total treatment cost of AMD could consistently be recovered**. A long-term supply agreement with Sasol could support the funding of a substantial portion of the capital requirements of AMD treatment facilities and will reduce the burden on funding from alternative sources and alternative funding models.

We remain available for further discussions on the technical and financial feasibility of the opportunity of supply of treated AMD to Sasol facilities.

Appendix A
Rand Water Users as Possible Recipients of Treated AMD

WESTERN BASIN
INSTITUTION/ORGANISATION
MOGALE CITY LOCAL MUNICIPALITY
RUSTENBURG MUNICIPALITY
RUSTENBURG PLATINUM MINE LTD
THEMBISILE LOCAL MUNICIPALITY
RANDFONTEIN MUNICIPALITY
MERAFONG
METSIMAHOLO LOCAL MUNICIPALITY
WESTONARIA LOCAL MUNICIPALITY
WESTERN PLATINUM LTD
ROYAL BAFOKENG NATION
WESTERN PLATINUM LTD KAREE MINE
KROONDAL PLATINUM MINES LTD.
NGWATHE LOCAL MUNICIPALITY - HEILBRON TOWN COUNCIL
MOGALE GOLD (PTY) LTD
RAINBOW CHICKEN FARMS (PTY) LTD
MADIBENG LOCAL MUNICIPALITY
JOHANNESBURG ELECTRICITY DEPARTMENT
FAR WEST RAND DOLOMATIC WATER ASSOCIATION
RANDFONTEIN ESTATES G M CO LTD
KNIGHTS GOLD RECOVERY CO (PTY)_LTD
CENTRAL BASIN
INSTITUTION/ORGANISATION
JOHANNESBURG WATER (PTY) LTD
RUSTENBURG MUNICIPALITY
MIDVAAL
CROWN MINES LTD
ROYAL BAFOKENG NATION
ERGO MINING (PTY) LTD
DR GEORGE MUKHARI HOSPITAL
SPOORNET
DEPT OF PUBLIC WORKS
NGWATHE LOCAL MUNICIPALITY - HEILBRON TOWN COUNCIL
ROTEK ENGINEERING (PTY) LTD - PAS
CENTRAL RAND GOLD S.A (PTY) LTD
THE AIRPORT COMPANY
NASIONALE PETROLEUMRAFFINEERDERS VAN S A
ENDERBROOKE INVEST (PTY) LTD T/A ERPM
AFRICAN PRODUCTS (PTY) LTD
JOHANNESBURG ELECTRICITY DEPARTMENT
HOLCIM (SOUTH AFRICA) (PTY) LTD
MEDICAL UNIVERSITY OF SOUTHERN AFRICA

PRETORIA METAALPERSWERKE (EDMS) BPK
IRENE DIEREPRODUKSIE-INSTITUUT
FIRST WESGOLD MINING (PTY) LTD
KLIPWATER ESTATES (PTY) LTD
GAUTENG DEPARTMENT OF AGRICULTURE CONSERVATION & ENVIRONMENT
LIFECARE SPECIAL HEALTH SERV. (PTY) LTD
SKUMBUZO BUSINESS ENTERPRISES
TRIPLE M METERING SERVICES CC
NORTH RAND TRAINING CENTRE
SCAW SOUTH AFRICA PTY LTD
DEPARTMENT OF PUBLIC WORKS
DURBAN ROODEPOORT DEEP LTD
ESKOMKOLLEGE
DENNY MUSHROOMS (PTY) LTD
JC GOLD MINING COMPANY (PTY) LTD NO 2
ESKOM VAALDRIEHOEK EIENDOMME
NAMPAK TISSUE A DIVISION OF (NPL)
EAST RAND SANTA CENTRE
SYNCRONISED LOGISTICAL SOLUTIONS CC
RAND REFINERY LTD
TWIN RIVERS HOME OWNERS ASSOCIATION
EASTERN BASIN
INSTITUTION/ORGANISATION
EKURHULENI METROPOLITAN MUNICIPALITY
CITY OF TSHWANE METROPOLITAN MUNICIPALITY
EMFULENI
GOVAN MBEKI MUNICIPALITY
IMPALA PLATINUM LTD
THE GROOTVLEI PROPRIETARY MINES
GOVAN MBEKI MUNICIPALITY
LESEDI LOCAL MUNICIPALITY
ERGO MINING (PTY) LTD
GROOTVLEI PROPRIETARY MINES LTD
IMPALA PLATINUM LTD REFINERIES
DELMAS LOCAL MUNICIPALITY
KNIGHTS GOLD RECOVERY CO (PTY)_LTD
KINROSS MINES LTD

Appendix B
Summary of Target Water Quality Ranges for Different Water User Sectors

Appendix B – Extract from the South African Water Quality Guidelines

This Appendix contains extracts from the following documents:

- South African Water Quality Guidelines for Domestic Water Use (DWAF, 1996a);
- South African Water Quality Guidelines for Industrial Water Use (DWAF, 1996b);
- South African Water Quality Guidelines for Irrigation Water Use (DWAF, 1996c);
- South African Water Quality Guidelines for Livestock Watering Use (DWAF, 1996d); and
- South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996e).

Refer to above mentioned reports which are available on the Department's website if any information is required beyond that which is provided here.

Table of Contents

1 Domestic use

1.1 pH

Table 1.1: Effects of pH on Aesthetics and Human Health

pH Range (pH units)	Effects
< 4.0	Severe danger of health effects due to dissolved toxic metal ions. Water tastes sour
4.0 - 6.0	Toxic effects associated with dissolved metals, including lead, are likely to occur at a pH of less than 6. Water tastes slightly sour
Target Water Quality Range 6.0 - 9.0	No significant effects on health due to toxicity of dissolved metal ions and protonated species, or on taste are expected. Metal ions (except manganese) are unlikely to dissolve readily unless complexing ions or agents are present. Slight metal solubility may occur at the extremes of this range. Aluminium solubility begins to increase at pH 6, and amphoteric oxides may begin to dissolve at a pH of greater than 8.5. Very slight effects on taste may be noticed on occasion
9.0 - 11.0	Probability of toxic effects associated with deprotonated species (for example, ammonium deprotonating to form ammonia) increases sharply. Water tastes bitter at a pH of greater than 9
> 11.0	Severe danger of health effects due to deprotonated species Water tastes soapy at a pH of greater than 11

1.2 Sulphate

Table 1.2: Effects of Sulphate on Aesthetics and Human Health

Sulphate Range (mg/ℓ as SO_4^{2-})	Effects
Target Water Quality Range 0 - 200	No health or aesthetic effects are experienced
200 - 400	Tendency to develop diarrhoea in sensitive and some non-adapted individuals. Slight taste noticeable
400 - 600	Diarrhoea in most non-adapted individuals. Definite salty or bitter taste
600 - 1 000	Diarrhoea in most individuals. User-adaptation does not occur. Pronounced salty or bitter taste
> 1 000	Diarrhoea in all individuals. User-adaptation does not occur. Very strong salty and bitter taste

1.3 Total Dissolved Solids

Table 1.3: Effects of TDS and EC on Human Health, Aesthetics, Household Distribution Systems and Water Heating Appliances

TDS Range (mg/ℓ)	EC Range (mS/m)	Aesthetic/Economic Effects	Health Effects
Target Water Quality Range 0 - 450	0 - 70	The taste threshold for dissolved salts in water is in the region of 45 mS/m (300 mg/ℓ TDS), hence a slight salty taste may be detected above this concentration. The threshold varies according to the salt composition Water with extremely low TDS concentrations may be objectionable because of its flat, insipid taste. No effects on plumbing or appliances	No health effects associated with the electrical conductivity of water are expected < 45 mS/m (300 mg/ℓTDS) The upper limit of this range takes into account the higher water consumption which may be expected in hot climates
450 - 1 000	70 - 150	Water has a noticeable salty taste, but is well tolerated. No effects on plumbing	No health effects are likely
1 000 - 2 000	150 - 300	Water has a marked, salty taste and would probably not be used on aesthetic grounds if alternative supplies are available. Some effects on plumbing and appliances, such as increased corrosion or scaling, may be expected	Consumption of water does not appear to produce adverse health effects in the short term
2 000 - 3 000	300 - 450	Water tastes extremely salty Corrosion and/or scaling of pipes and appliances will increase	Short-term consumption may be tolerated, but with probable disturbance of the body's salt balance
> 3 000	> 450	Water tastes extremely salty and bitter. Effects such as corrosion and/or scaling increase	Short-term consumption leads to disturbance of the body's salt balance. At high concentrations, noticeable short-term health effects can be expected

1.5 Calcium

Table 1.4: Effects of Calcium on Personal Hygiene, Household Distribution Systems and Water Heating Appliances

Calcium Range (mg/ℓ as Ca)	Effects
Target Water Quality Range: 0 - 32	No health effects. No scaling evident. Possible corrosive effects < 16 mg/ℓ
32 - 80	No health effects. Increased scaling problems Lathering of soap impaired
> 80	No health effects. Severe scaling problems Lathering of soap severely impaired

1.6 Magnesium

Table 1.5: Effects of Magnesium on Aesthetics and Human Health

Magnesium Range (mg/ℓ as Mg)	Effects
Target Water Quality Range: 0 - 30	No bitter taste. No scaling problems. No health effects
30 - 50	No bitter taste. Slight scaling problems may occur. No health effects
50 - 70	No bitter taste; No health effects; Scaling problems
70 - 100	Slight bitter taste. Taste threshold for magnesium is D 70 mg/ℓ. Scaling problems. Diarrhoea in sensitive users
100 - 200	Water aesthetically unacceptable because of bitter taste. Increased scaling problems. Diarrhoea in most new users if sulphate present
200 - 400	Severe scaling problems. Diarrhoea in all new users
> 400	Severe scaling problems. Diarrhoea in all new users. Health problems may occur

1.7 Cadium

Table 1.6: Effects of Cadmium on Human Health

Cadmium Range (µg/ℓ)	Effects
Target Water Quality Range: 0 - 5	No observable health effects
As a precautionary measure, it is recommended that the TWQR not be exceeded because of the potentially acute and/or irreversible effects of cadmium on human health	

5 - 10	No observable health effects, unless zinc nutritional status is suboptimal, or in smokers, where there is a slight risk of subclinical effects on long-term exposure
10 - 20	Threshold for health damage with continuous exposure. Single incidence of exposure will not have observable effects
20 - 1 000	Danger of kidney damage with long-term exposure. Brief exposure, for less than one week should not cause any noticeable damage. Exposure should not exceed one week
> 1 000	Danger of acute cadmium poisoning, with the possibility of fatalities

1.8 Chromium

Table 1.7: Effects of Chromium(VI) on Human Health

Chromium(VI) Range (mg/ℓ)	Effects
Target Water Quality Range: 0 - 0.050	Risk of cancer induction insignificant No toxic or aesthetic effects
As a precautionary measure it is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of chromium(VI) on human health	
0.05 - 1.0	Possible risk of induction of gastrointestinal cancer following long-term exposure
1.0 - 5.0	Undesirable taste, slight nausea, and increasing risk of cancer induction
> 5.0	Risk of acute toxicity

1.9 Iron

Table 1.8: Effects of Iron on Aesthetics, Human Health and Household Distribution Systems

Iron Range (mg/ℓ)	Effects
Water Quality Target Range: 0 - 0.1	No taste, other aesthetic or health effects associated with consumption and use
0.1 - 0.3	Very slight effects on taste and marginal other aesthetic effects Deposits in plumbing with associated problems may begin to occur. No health effects; the water is generally well tolerated
0.3 - 1.0	Adverse aesthetic effects (taste) gradually increase as do possible problems with plumbing. No health effects

1 - 10	Pronounced aesthetic effects (taste) along with problems with plumbing. Slight health effects expected in young children, and sensitive individuals
10 - 30	Severe aesthetic effects (taste) and effects on the plumbing (slimy coatings). Slight iron overload possible in some individuals. Chronic health effects in young children and sensitive individuals in the range 10 - 20 mg/ℓ, and occasional acute effects toward the upper end of this range
30 - 100	As above Long-term health effects gradually increase
100 - 300	As above Chronic health effects. Acute toxicity may begin to appear
300 - 3 000	As above Chronic and acute health effects. Accidental iron poisoning from water is rare
3 000 - 30 000	As above Lethal toxicity occurs

1.10 Manganese

Table 1.9: Effects of Manganese on Aesthetics and Human Health

Manganese Range (mg/ℓ)	Effects
Target Water Quality Range: 0 - 0.05	No health or aesthetic effects; marginal aesthetic problems occasionally found in the 0.02-0.05 mg/ℓ range
0.05 - 0.10	Tolerable range, although slight staining may occur. No health effects
0.10 - 0.15	Threshold for significant staining and taste problems. No health effects
0.15 - 1.0	Increasingly severe staining and taste problems. No health effects
1.0 - 2.0	Very severe staining and taste effects. No health effects
2.0 - 5.0	Extreme staining, likely to be aesthetically unacceptable to a large proportion of users. No health effects
5 - 14	Unacceptable levels of aesthetic effects. Health effects rare
14 - 20	Very severe, aesthetically unacceptable staining. Domestic use unlikely due to adverse aesthetic effects. Some chance of manganese toxicity under unusual conditions
> 20	Domestic use unlikely due to extreme aesthetic effects Chronic toxicity; at high concentrations, possible acute effects

2 Livestock watering

2.1 Sulphate

Table 2.1: Effects of Sulphate on the Health of Livestock

Sulphate Range (mg/ℓ)	Effects
Target Water Quality Range: 0 - 1 000	No adverse effects
1 000 - 1 500	**Adverse chronic effects may occur, such as** - diarrhoea; - adverse palatability effects (water and feed intake decline); - poor productivity These effects will most likely be temporary and normal production should continue within a few days once the stock are adapted. Young stock are less tolerant than mature stock
1 500 - 2 000	An increased possibility of adverse chronic effects in mature stock and a possibility of acute effects such as severe diarrhoea and refusal to consume water (young stock) may occur. If, however, the stock have been adapted to sulphate concentrations close to the upper limit of the TWQR, then adaptation to this range should be within a few days
> 2 000	**Adverse chronic effects and acute effects may occur with both mature and young stock.** Depending on the production system, nutritional status, degree of adaptation to sulphate waters, and antagonistic/synergistic interactions of other salts present in the water, concentrations far in excess of this concentration may be tolerated without adverse effects

2.2 Total Dissolved Solids

Table 2.2: Effects of TDS on Livestock Production

TDS mg/ℓ	Sheep	Beef	Horses	Dairy	Pigs and Poultry
0 - 1 000	" " " "	" " " "	" " " "	" " " "	" " " "
1 000 - 2 000	" " " "	" " " "	" " " "	" " " !	" " " !
2 000 - 3 000	" " " "	" " " !	" " " !	" " " !	" " ! !
3 000 - 4 000	" " " !	" " " !	" " ! !	" " ! !	" ! ! !
4 000 - 5 000	" " " !	" " " !	" " ! !	" ! ! !	! ! ! !
5 000 - 6 000	" " " !	" " " !	" " ! !	" ! ! !	! ! ! !
6 000 - 7 000	" " ! !	" " ! !	" ! ! !	! ! ! !	! ! ! !
7 000 - 10 000	" " ! !	" ! ! !	! ! ! !	! ! ! !	! ! ! !
10 000 - 13 000	" " ! !	! ! ! !	! ! ! !	! ! ! !	! ! ! !
> 13 000	" ! ! !	! ! ! !	! ! ! !	! ! ! !	! ! ! !

Symbol	**Effects (E) are dependent on the Action (A)**	
" " " "		**Target Water Quality Range**
	E A	No significant adverse effects. Immediate access allowed without any previous exposure to saline waters.
' " " !	**E A**	Possible initial reluctance to drink, but should be temporary. No significant adverse effects. Immediate access allowed with previous exposure to saline waters (TDS of approximately 50 %).
	E A	Initial reluctance to drink may lead to a decline in water intake and, subsequently, production. However, the stock should adapt within a relatively short period of time (within a week) and return to normal production level. Immediate access allowed without any previous exposure to saline waters.
" " ! !	**E A**	Care should be taken when allowing stock access to these waters, specifically for intensive systems. Initial reluctance to drink may lead to a decline in water intake and subsequently production. However, the stock should adapt to the water within a relatively short period of time (within a week) and return to normal production levels. Increased need to adapt stock to salinity levels. Immediate access allowed only with previous exposure to saline waters (TDS of approximately 50%).
" ! ! !	**EA**	Production will in all likelihood decline significantly. Stock should survive (at maintenance level) and recover when offered water with TDS within the TWQR, provided exposure is not too long. Increased need to adapt stock to salinity levels. Some species can tolerate once adapted (see text). Immediate access allowed only with previous exposure to saline waters (TDS of approximately 50%) for limited periods of time.
! ! ! !	**EA**	Extreme caution should be taken when allowing stock access to these ranges. Some species can tolerate once adapted (see text). No immediate access allowed. Stock must be adapted incrementally to water source.

2.3 Calcium

Table 2.3: Effects of Calcium on the Health of Livestock

Calcium Range (mg/ℓ)	Effects (All species)
Target Water Quality Range: 0 - 1 000	No adverse effects
1 000 - 2 000	**Adverse chronic effects such as hypercalcemia, and adverse palatability effects such as a decline in water and feed intake and weight loss may occur, but are unlikely if:** - stock have adapted to the water - feed concentration and ratios of Ca:P are within nutritional limits - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as water requirement and synergistic and antagonistic nutritional factors **Ruminants can tolerate a wider Ca:P range than monogastrics**

> 2 000	**Adverse chronic effects may occur (see above), although short term exposure may be tolerated, depending on whether:** - stock have adapted to water - feed concentrations and ratios of Ca:P are within nutritional limits - water requirement

2.4 Magnesium

Table 2.4: Effects of Magnesium on the Health of Livestock

Magnesium Range (mg/ℓ)	**Effects**	
	Ruminants	**Non-ruminants**
Target Water Quality Range: 0 - 500	No adverse effects	No adverse effects
500 - 1 000	Adverse chronic effects such as lethargy and decreased feed intake may occur, but will most likely be temporary and normal production should continue once stock have adapted; see TDS	Adverse chronic and acute effects such as loss of co- ordination, decreased feed intake and performance and diarrhoea may occur May be tolerated for short exposure time depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will, in all likelihood, decline; see TDS
> 1 000	Adverse chronic effects as above, and acute effects such as diarrhoea may occur. May be tolerated for shorter exposure time depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will, in all likelihood, decline; see TDS	Adverse chronic and acute effects (as above) may occur. May be tolerated for short exposure time depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will, in all likelihood, decline; see TDS

2.5 Cadmium

Table 2.5: Effects of Cadmium on Livestock Health

Cadmium Range (mg/ℓ)	**Effects (All livestock)**
Target Water Quality Range: 0 - 0.01	No adverse effects

0.01 - 0.02	**Adverse chronic effects** such as anaemia, testicular degeneration, reduced feed intake and milk production and reduced growth may occur, but are unlikely if: - exposure is short term - adequate intake of dietary protein, calcium and phosphorus - feed concentration of cadmium is normal **Adverse acute effects** such as abortions, still births, hepato- and nephrotoxicity may occur, but suckling and pregnant livestock are principally at risk Could even be tolerated in the long term, depending on site-specific factors such as water requirement and Ca:P concentrations
> 0.02	**Adverse chronic and acute effects (as above) may occur, although** short-term exposure could be tolerated depending on: - feed concentrations of cadmium - adequate intake of dietary protein, calcium and phosphorus - water requirement

2.6 Chromium

Table 2.6: Effects of Chromium(VI) on Livestock Health

Chromium(VI) Range (mg/ℓ)	**Effects**
	All species
Target Water Quality Range: 0 - 1	No adverse effects
1 - 2	**Adverse chronic effects such as diarrhoea may occur, but are unlikely if:** - feed concentrations are normal - exposure is short term Can even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 2	**Adverse chronic effects such as diarrhoea and possible carcinogenic effects may occur, although** short-term exposure could be tolerated depending on site-specific factors such as nutritional interactions and water requirement

2.7 Cobalt

Table 2.7: Effects of Cobalt on the Health of Livestock

Cobalt Range(mg/ℓ)	**Effects**
	All livestock
Target Water Quality Range: 0 - 1	No adverse effects

1 - 2	**Adverse chronic effects such as inappetence and weight loss may occur, but are unlikely if:** - feed concentrations are normal - exposure is short term Could even be tolerated in the long term, depending on site- specific factors such as nutritional interactions and water requirement
> 2	**Adverse chronic effects (as above) may occur, although** short-term exposure can be tolerated depending on site- specific factors such as nutritional interactions and water requirement

2.8 Iron

Table 2.8: Effects of Iron on the Health of Livestock

Iron Range (mg/ℓ)	**Effects**
	All livestock
Target Water Quality Range: 0 - 10	No adverse effects
10 - 50	**Adverse chronic effects such as liver and pancreas damage, may occur, but are unlikely if:** - feed concentrations are normal, and - exposure is short term Could even be tolerated in the long term, depending on site-specific factors, such as adequate intake of phosphate and water requirement
> 50	**Adverse chronic and acute effects such as diarrhoea, vomiting, acidosis and respiratory failure and liver and pancreas damage respectively, may occur, although** short-term exposure could be tolerated depending on site- specific factors such as adequate intake of phosphate and water requirement

2.9 Manganese

Table 2.9: Effects of Manganese on the Health of Livestock

Manganese Range (mg/ℓ)	**Effects**
	All livestock
Target Water Quality Range: 0 - 10	No adverse effects

10 - 50	**Adverse chronic effects such as weight loss due to inappetence may occur, but are unlikely if:** - feed concentrations are normal, and - exposure is short term. Could even be tolerated in the long term, depending on site-specific factors such as adequate intake of calcium, phosphorus and iron and water requirement
> 50	**Adverse chronic effects such as weight loss and anaemia (where iron intake is not adequate) may occur, although** short-term exposure could be tolerated depending on site-specific factors (as above)

3 Aquatic ecosystems

3.1 pH

Table 3.1: The criteria for pH in aquatic ecosystems are:

Water Resource	Target Water Quality Range
All aquatic ecosystems	pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0.5 of a pH unit, **or** by > 5 %, **and should be assessed by whichever estimate is the more conservative**.

3.2 Total dissolved Solids

Table 3.2: The TWQR for TDS is stated in terms of case- and site-specific TDS concentrations. In all cases, local conditions should be determined (i.e. TDS concentrations, variability and seasonal changes) before water quality criteria are set.

Water Resource	Target Water Quality Range
All inland waters	TDS concentrations should not be changed by > 15% from the normal cycles of the water body under unimpacted conditions at any time of the year; **and** The amplitude and frequency of natural cycles in TDS concentrations should not be changed.

3.4 Cadmium

Table 3.3.1: The TWQR and criteria for total cadmium at different water hardness (mg $CaCO_3$/ℓ) in aquatic ecosystems are:

TWQR and Criteria	Water Hardness - Cadmium concentration			
	< 60 (Soft)	60-119 (Medium)	120-180 (Hard)	> 180 (Very hard)
Target Water Quality Range (TWQR)	0.15	0.25	0.35	0.40
Chronic Effect Value (CEV)	0.3	0.5	0.7	0.8
Acute Effect Value (AEV)	3	6	10	13

Table 3.3.2: Recommended Cadmium Criteria and TWQR (mg/ℓ) for Cold-water adapted Fish Species

TWQR and Criteria	Water Hardness (mg $CaCO_3$/ℓ)			
	< 60 (Soft)	60-119 (Medium)	120-180 (Hard)	> 180 (Very hard)
Target Water Quality Range (TWQR)	0.07	0.1	0.15	0.17
Chronic Effect Value (CEV)	0.15	0.19	0.29	0.34
Acute Effect Value (AEV)	1.8	2.8	5.1	6.2

3.5 Chromium

Table 3.4.1: TWQR and criteria for dissolved chromium(VI) in aquatic ecosystems

TWQR and Criteria	Chromium(VI) concentration (µg/ℓ)
Target Water Quality Range (TWQR)	< 7
Chronic Effect Value (CEV)	14
Acute Effect Value (AEV)	200

Table 3.4.2: TWQR and criteria for dissolved chromium(III) in aquatic ecosystems

TWQR and Criteria	Chromium(III) concentration (µg/ℓ)
Target Water Quality Range (TWQR)	< 12
Chronic Effect Value (CEV)	24
Acute Effect Value (AEV)	340

3.6 Iron

Table 3.5: TWQR for iron in aquatic ecosystems

Target Water Quality Range (TWQR)
The iron concentration should not be allowed to vary by more than 10 % of the background dissolved iron concentration for a particular site or case, at a specific time.

3.7 Manganese

Table 3.6: TWQR and criteria for dissolved manganese in aquatic ecosystems

TWQR and Criteria	Manganese concentration (µg/ℓ)
Target Water Quality Range (TWQR)	< 180
Chronic Effect Value (CEV)	370
Acute Effect Value (AEV)	1 300

4 Irrigation use

4.1 pH

Table 4.1: Effects of pH on Crop Yield and Quality, Sustainability of the Soil and Irrigation Equipment

pH Range	Crop Yield and Quality	Sustainability	Irrigation Equipment
< 6.5	Increasing problems with foliar damage when crop foliage is wet. This could give rise to yield reduction or a decrease in the quality of marketable materials	Increasing problems with the availability of several micro- and macro-nutrients in toxic concentrations are experienced in this range over the long term	Increasing problems with corrosion of metal and concrete in irrigation equipment are experienced in this range Practically no problems experienced with clogging of drip irrigation systems
Target Water Quality Range: 6.5 - 8.4	Even when crop foliage is wetted, this should not cause foliar damage in plants which will result in a yield reduction or a decrease in the quality of marketable products.	Soil pH within this range does not present major problems with either unavailability of plant nutrients or toxic levels of elements.	Mostly no major problem with either corrosion or encrustation of irrigation equipment is experienced within this range (see Total Hardness). Slight to moderate problems with the clogging of drip irrigation systems.
> 8.4	Increasing problems with foliar damage affecting yield or decrease in visual quality of visual marketable products are experienced in this range.	Increasing problems with the unavailability of several micro- and macro-nutrients are experienced within this range over the long term.	Increasing problems with encrustation of irrigation pipes and clogging of drip irrigation systems are experienced in this range.

4.2 Total dissolved solids

Table 4.2: Effects of TDS/EC on Crop Yield

EC Range (mS/m)	Crop Yield
Target Water Quality Range: < 40	Should ensure that salt-sensitive crops can be grown without yield decreases when using low frequency irrigation systems. A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be avoided
40 - 90	A 95 % relative yield of moderately salt-sensitive crops can be maintained by using a low-frequency irrigation system. A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be avoided
90 - 270	A 90 % relative yield of moderately salt-tolerant crops can be maintained by using a low-frequency application system. A leaching fraction of up to 0.15 may be required and wetting of the foliage of sensitive crops should be avoided
270 - 540	A 80 % relative yield of moderately salt-tolerant crops can be maintained provided that a high-frequency irrigation system is used. A leaching fraction of up to 0.2 may be required and wetting of the foliage of sensitive crops should be avoided
> 540	These waters can still be used for irrigation of selected crops provided sound irrigation management is practised and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive and the likelihood of sustainable irrigation decreases rapidly

4.3 Cadmium

Table 4.3: Effects of Cadmium on Crop Yield and Quality

Concentration Range (mg/ℓ)	Crop Yield and Quality
Target Water Quality Range: < 0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/ℓ in nutrient solutions. Conservative limits are needed because of cadmium's potential for accumulation in plants and soils to concentrations that may be toxic to humans and animals
0.01 - 0.05	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 0.05	Acceptable for irrigation only over the short term on a site-specific basis

4.5 Chromium

Table 4.4: Effects of Chromium(VI) on Crop Yield and Quality

Concentration Range (mg/ℓ)	Crop Yield and Soil Sustainability
Target Water Quality Range < 0.10	Depending on plant species, nutrient solutions containing 0.1 mg/ℓcan induce chromium toxicity
0.10 - 1.0	Maximum acceptable concentration for fine-textured neutral to alkaline soils
> 1.0	Acceptable for irrigation only over the short term on a site- specific basis

4.6 Cobalt

Table 4.5: Effects of Cobalt on Crop Yield and Quality

Concentration Range (mg/ℓ)	Crop Yield and Quality
Target Water Quality Range: < 0.05	A satisfactory concentration for continuous application is 0.05 mg/ℓ; 0.1 mg/ℓis near the toxicity threshold of many plants. Generally cobalt does not accumulate in edible parts of plants to levels that are dangerous to consumers
0.05 - 5.0	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 5.0	Acceptable for irrigation only over the short term on a site-specific basis

4.7 Iron

Table 4.6.1: Effects of Iron on Crop Yield and Quality

Concentration Range (mg/ℓ)	Crop Yield and Quality
Target Water Quality Range: < 5.0	Not toxic to root uptake by plants in aerated soils. Plant foliage damaged or blemished by iron deposits when wetted during irrigation
5.0 - 20.0	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 20.0	Exceeds the maximum acceptable concentration used by most international guidelines

Table 4.6.2: Effects of Iron on Water Uses involving Irrigation Equipment

Concentration Range (mg/ℓ)	Clogging of Irrigation Equipment
Target Water Quality Range: < 0.2	Only minor problems encountered with clogging of drip irrigation systems
0.2 - 1.5	Moderate problems encountered with clogging of drip irrigation systems
> 1.5	Severe problems encountered with clogging of drip irrigation systems

4.8 Manganese

Table 4.7.1: Effects of Manganese on Crop Yield and Soil Sustainability

Concentration Range (mg/ℓ)	Crop Yield and Soil Sustainability
Target Water Quality Range: < 0.02	Depending on plant species, nutrient solutions containing a few tenths of a mg/ℓcan induce manganese toxicity
0.02 - 10.0	Maximum acceptable concentration for fine-textured neutral to alkaline soils
> 10.0	Acceptable for irrigation only over the short term on a site-specific basis

Table 4.7.2: Effects of Manganese on Water Uses involving Irrigation Equipment

Concentration Range (mg/ℓ)	Clogging of Irrigation Equipment
Target Water Quality Range: < 0.1	Only minor problems encountered with clogging of drip irrigation systems
0.1 - 1.5	Moderate problems encountered with clogging of drip irrigation systems
> 1.5	Severe problems encountered with clogging of drip irrigation systems

5 Industrial use

5.1 pH

Table 5.1: Effects of pH on Category 1 Industrial Processes

Range of pH (pH units)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
< 6.0	Major to moderate and extensive damage due to highly corrosive environment	No effect on highly acidic processes; major pH adjustment required for alkaline processes	Potential for product impairment due to corrosion or corrosion products high	Major to minor pH adjustment required before disposal
6.0 - 7.0	Moderate to minor damage due to tendency for corrosion	Little interference with acidic or neutral processes; moderate pH adjustment required for alkaline processes	Potential for product impairment due to corrosion or corrosion products mild to moderate	No problems in waste handling
7.0 -8.0 **Target Water Quality Range**	No or little damage due to corrosion or scaling	No effect on most industrial processes. Minor to major adjustment necessary for both highly acidic and alkaline processes	No or little impairment of product quality due to corrosion, scaling or deposits	No problems in waste handling
8.0 - 9.5	Minor to moderate damage due to scaling possible	Mild effect on alkaline and neutral processes; moderate to major pH adjustment for highly acidic processes	Potential for product impairment due to scaling or deposits mild to moderate	No problems in waste handling
> 9.5	Moderate to major and extensive damage due to very high scaling tendency	No effect on highly alkaline processes; mild to major pH adjustment required for acidic processes	Potential for product quality impairment due to scaling or deposits high	Minor to major pH adjustment required before disposal

Table 5.1.2: Examples of Category 1 Industrial Processes

Cooling Water	Steam Generation	Process Water	Wash Water
Evaporative cooling (high recycle)	High pressure boilers (Demineralisation- plant feed water)	Phase separation Petrochemicals Pharmaceuticals	Washing with no residuals (electronic parts)

Table 5.1.3: Effects of pH for Category 2 Industrial Processes

Range of pH (pH units)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
< 5.0	Major to minor and extensive damage due to highly corrosive environment	No effect on highly acidic processes; major pH adjustment required for alkaline processes	Potential for product impairment due to corrosion or corrosion products high	Major to minor pH adjustment required before disposal
5.0 - 6.5	Moderate to minor damage due to tendency for corrosion	Little interference with acidic or neutral processes; moderate pH adjustment required for alkaline processes	Potential for product impairment due to corrosion or corrosion products mild to moderate	pH adjustment may be required before disposal
6.5 - 8.0 **Target Water Quality Range**	No or little damage due to corrosion or scaling	No effect on most industrial processes; minor to major adjustment necessary for both highly acidic or alkaline processes	No or little impairment of product quality due to corrosion, scaling or deposits	No problems in waste handling
8.0 - 10.0	Minor to moderate damage due to scaling possible	Mild effect on alkaline and neutral processes; moderate to major pH adjustment for highly acidic processes	Potential for product impairment due to scaling or deposits mild to moderate	pH adjustment may be required before disposal
> 10.0	Major and extensive damage due to very high scaling tendency	No effect on highly alkaline processes; mild to major adjustment required for acidic processes	Potential for product impairment due to scaling or deposits high	Minor to major pH adjustment required before disposal

Table 5.1.4: Examples of Category 2 Processes

Heat Exchange	Steam Generation	Process Water	Product Water
Evaporative cooling (high recycle) Solution cooling Water heating	High pressure boilers (demineralisation - plant feed water)	Solvent agent Heat transfer medium Humidification Lubrication Gas cleaning	Beverages Dairy Petrochemical

Table 5.1.5: Effects of pH on Category 3 Industrial Processes

Range of pH (pH units)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
< 5.0	Major to minor and extensive damage due to highly corrosive environment	No effect on highly acidic processes; major pH adjustment required for alkaline processes	Potential for product impairment due to corrosion or corrosion products high	Major to minor pH adjustment required before disposal
5.0 - 6.5	Major and extensive damage due to highly corrosive environment	Little interference with acidic or neutral processes; moderate pH adjustment required for alkaline	Potential for product impairment due to corrosion or corrosion products mild to moderate	pH adjustment may be required before disposal
6.5 - 8.0 **Target Water Quality Range**	No or little damage due to corrosion or scaling	No effect on most industrial processes; minor to major adjustment necessary for both highly acidic or alkaline processes	No or little impairment of product quality due to corrosion, scaling or deposits	No problems in waste handling
8.0 - 10.0	Minor to moderate damage due to scaling possible	Mild effect on alkaline and neutral processes; moderate to major pH adjustment for highly acidic processes	Potential for product impairment due to scaling or deposits mild to moderate	pH adjustment may be required before disposal
> 10.0	Major and extensive damage due to scaling and/or deposits	No effect on alkaline processes; Mild to major pH adjustment required for acidic processes	Potential for product quality impairment due to scaling or deposits high	Minor to major pH adjustment required before disposal

Table 5.1.6: Examples of Category 3 Industrial Processes

Cooling Water	Steam Generation	Process Water	Product water	Utility Water
Evaporative cooling (once through) Bearing cooling Mould cooling	Low pressure boilers (softening process feed water)	Solvent Dilution agent Transport agent Gland seal Vacuum seal Lubrication Descaling (iron and steel industry) Gas scrubbing	Beverage Food products Baking and confectionery Chemicals	Surface washing (table tops, walls) Domestic use Fire fighting

Table 5.1.7: Effects of pH on Category 4 Industrial Processes

Range of pH (pH units)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
< 5.0	Potential for damage high due to high corrosive tendency	No significant effect on processes	No significant effect on product quality	Major to minor pH adjustment required before disposal
5.0 - 10.0 **Target Water Quality Range**	No significant damage under most circumstances but potential for corrosion or scaling at extremes of range	No effect on processes	No effect on product quality	No problems in waste handling
> 10.0	Potential for damage high due to high scaling tendency	No significant effect on processes	No significant effect on product quality	Minor to major pH adjustment required before disposal

Table 5.1.8: Examples of Category 4 Industrial Processes

Cooling Water	Process Water	Utility Water	Wash Water
Ash quenching	Transport agent	Dust suppression Fire fighting Irrigation	Rough washing (floors, rough apparatus, trucks, raw materials)

5.2 Sulphate

Table 5.2.1: Effects of Sulphate on Category 1 Industrial Processes

Range of concentration (mg SO_4/ℓ)	**Damage to equipment and structures**	**Interference with processes**	**Product quality**	**Complexity of waste handling**
0 - 30 **Target Water Quality Range**	No or negligible damage as a result of corrosion, concrete degradation or scaling	No interference with processes expected	No impairment of product quality	No problems except for disposal of highly saline effluents from low frequency regeneration of demineralisation plant
30 - 80	Negligible to minor damage as a result of corrosion, scaling	Some interference with processes may be expected	Slight to moderate impairment of product quality	No problems except for disposal of highly saline effluents from low to moderate frequency regeneration of demineralisation plant
80 - 150	Moderate damage as a result of corrosion, scaling	Moderate interference with processes may be expected	Moderate to significant impairment of product quality	No problems except for disposal of highly saline effluents from moderate frequency regeneration of demineralisation plant
> 150	Moderate to major damage as a result of corrosion, scaling	Moderate to major interference with processes may be expected	Significant to severe impairment of product quality may occur	No problems except for disposal of highly saline effluents from moderate to high frequency regeneration of demineralisation plant

Table 5.2.2: Effects of Sulphate on Category 2 Industrial Processes

Range of concentration (mg SO_4/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0 - 80 **Target Water Quality Range**	No or negligible damage as a result of corrosion, scaling	No interference with processes expected	No impairment of product quality	No problems except for disposal of highly saline effluent from low frequency regeneration of demineralisation plant
80 - 150	Negligible to minor damage as a result of corrosion, scaling	Some interference with processes may be expected	Slight to moderate impairment of product quality due to precipitation of sulphates	No problems except for disposal of highly saline effluent from low to moderate frequency regeneration of demineralisation plant
150 - 250	Moderate damage as a result of corrosion, scaling	Moderate interference with processes may be expected	Moderate to significant impairment of product quality due to precipitation of sulphates	No problems except for disposal of highly saline effluent from moderate frequency regeneration of demineralisation plant
> 250	Moderate to major damage as a result of corrosion, scaling, or concrete degradation	Moderate to major interference with processes may be expected	Significant to major impairment of product quality may be expected through precipitation	No problems except for disposal of highly saline effluent from moderate to high frequency regeneration of demineralisation plant

Table 5.2.3: Effects of Sulphate on Category 3 Industrial Processes

Range of concentration (mg SO_4/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0 - 200 **Target Water Quality Range**	No or negligible damage as a result of corrosion, scaling	No or little interference with processes may be expected	No impairment of product quality	No problems in waste handling
200 - 300	Mild to moderate damage through corrosion, scaling	Mild to moderate interference with processes may be expected	Slight to moderate impairment of product quality	No problems in waste handling
> 300	Significant to major damage as a result of corrosion, scaling or concrete degradation	Significant to major interference with processes may be expected	Significant to major impairment to product quality due to precipitation of sulphates, unpleasant tastes and severe flavour changes may be expected	No problems except for disposal of highly saline effluents from moderate to high frequency regeneration of demineralisation plant

Table 5.2.4: Effects of Sulphate on Category 4 Industrial Processes

Range of concentration (mg SO_4/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0 - 500 **Target Water Quality Range**	No damage to equipment and structures expected, provided exposure to water within this range is not excessive. Longer exposures to concentrations at upper end of range may result in corrosion, scaling or concrete degradation	No interference with processes expected	No impairment of product quality	No problems in waste handling
> 500	Damage to piping carrying water for Category 4 processes may be experienced due to corrosion and scaling; severe damage to concrete structures due to concrete degradation may be experienced	Little interference with Category 4 processes expected	Quality of products from Category 4 processes little affected, apart from encrustation with salts following evaporation	Major reduction in sulphate content may be required to comply with local or General Standards for discharges

5.3 Total dissolved solids

Table 5.3.1: Effects of TDS and EC for Category 1 Industrial Processes

Range of TDS (mg/ℓ) EC (mS/m)	**Damage to equipment and structures**	**Interference with processes**	**Product quality**	**Complexity of waste handling**
TDS 0 - 100 EC 0 - 15 **Target Water Quality Range**	No or negligible damage as a result of corrosion, scaling or fouling	No process interference expected	No effect on product quality	No problems except for disposal of highly saline effluents from low frequency regeneration of demineralisation plant
TDS 100 - 200 EC 15 - 30	Minor damage as a result of corrosion, scaling or fouling possible	Little or minor interference with processes as a result of precipitation possible	Slight to minor product impairment as a result of precipitation of salts	No problems except for disposal of highly saline effluents from low to moderate frequency regeneration of demineralisation plant
TDS 200 - 450 EC 30 - 70	Moderate damage through corrosion, scaling or fouling possible	Moderate to significant interference with processes possible	Moderate impairment of product quality as a result of precipitation of salts	No problems except for disposal of highly saline effluents from moderate frequency regeneration of demineralisation plant
TDS > 450 EC > 70	Significant to major damage likely as a result of corrosion, scaling or fouling	Significant to major interference with processes may be expected	Significant to major impairment to products may be expected	No problems except for disposal of highly saline effluents from moderate to high frequency regeneration of demineralisation plant

Table 5.3.2: Effects of TDS and EC for Category 2 Industrial Processes

Range of TDS (mg/ℓ)	**Damage to equipment and structures**	**Interference with processes**	**Product quality**	**Complexity of waste handling**
TDS 0 – 200 EC 0 – 30 **Target Water Quality Range**	No or negligible damage as a result of corrosion, scaling or fouling	No process interference expected	No effect on product quality	No problems except for disposal of highly saline effluents from low frequency regeneration of demineralisation plant
TDS 200 - 350	Minor damage as a	Little or minor	Slight to minor	No problems except

EC 30 - 50	result of corrosion, scaling or fouling possible	interference with processes as a result of precipitation possible	product impairment as a result of salt precipitation possible	for disposal of highly saline effluents from low to moderate frequency regeneration of demineralisation plant
TDS 350 – 800 EC 50 - 120	Moderate damage through corrosion, scaling and fouling possible	Moderate to significant interference with processes possible	Moderate impairment of product quality due to precipitation possible	No problems except for disposal of highly saline effluents from moderate frequency regeneration of demineralisation plant
TDS > 800 EC > 120	Significant to major damage likely as a result of corrosion, scaling, or fouling	Significant to major interference with processes expected	Significant to major impairment to products expected	Major reduction in salt content required to comply with local or General Standards for discharges

Table 5.3.3: Effects of TDS and EC for Category 3 Industrial Processes

Range of TDS (mg/ℓ) EC (mS/m)	**Damage to equipment and structures**	**Interference with processes**	**Product quality**	**Complexity of waste handling**
TDS 0 – 450 EC 0 – 70 **Target Water Quality Range**	No or negligible damage as a result of corrosion, scaling or fouling	No or little interference with processes expected	No effect on product quality	No problems except for disposal of highly saline effluents from low to moderate frequency regeneration of demineralisation plant
TDS 450 – 800 EC 70 - 120	Minor to moderate damage through corrosion, scaling or fouling possible	Mild to moderate interference with processes possible	Mild to moderate impairment of product quality due to salt precipitation, taste and flavour changes	No problems except for disposal of highly saline effluents from moderate frequency regeneration of demineralisation plant
TDS 800 - 1 600 EC 120 -250	Moderate to significant damage likely as a result of corrosion, scaling or fouling	Moderate to significant interference with processes expected	Moderate to significant impairment to products expected	Reduction in salt content of effluents may be required to comply with local or General Standards for discharges
TDS > 1 600 EC > 250	Significant to major damage likely as a result of corrosion, scaling or fouling	Significant to major interference with processes expected	Significant to major impairment to product quality expected	Moderate to major reduction in salt content of effluents to comply with local or General Standards for discharges

Table 5.3.4: Effects of TDS and EC for Category 4 Industrial Processes

Range of TDS (mg/ℓ) EC (mS/m)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
TDS 0 - 1 600 EC 0 - 250 **Target Water Quality Range**	No or negligible damage expected provided exposure not excessive	No process interference expected	No effect on product quality	No problems in waste handling
TDS > 1 600 EC > 250	Major damage likely due to corrosion, scaling or fouling	No or little process interference expected	Minor impairment to product quality due salt encrustation following evaporation	Minor to major reduction in salt content of effluents required to comply with local or General Standards for discharges

5.4 Iron

Table 5.4.1: Effects of Iron on Category 1 Industrial Processes

Range of concentration (mg Fe/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 0.1 **Target Water Quality Range**	No damage due to precipitation of iron compounds	No interference with processes	No effect on product quality	No problems in waste handling
0.1 - 0.3	Minor to moderate damage due to precipitation of iron compounds	Negligible to minor interference with processes	Negligible to minor impairment of product quality	No problems in waste handling
0.3 - 1.0	Moderate to significant damage due to precipitation of iron compounds	Moderate to significant interference with processes	Moderate to significant impairment of product quality	No problems in waste handling
> 1.0	Significant to major damage due to precipitation of iron compounds	Significant to major interference with processes	Significant to major impairment of product quality	Treatment may be required to precipitate excessive iron in effluents

Table 5.4.2: Effects of Iron on Category 2 Industrial Processes

Range of concentration (mg Fe/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 0.2 **Target Water Quality Range**	No damage due to precipitation of iron compounds	No interference with processes	No effect on product quality	No problems in waste handling
0.2 - 0.5	Minor to moderate damage due to precipitation of iron compounds	Negligible to minor interference with processes	Negligible to minor impairment of product quality	No problems in waste handling
0.5 - 2.0	Moderate to significant damage due to precipitation of iron compounds	Moderate to significant interference with processes	Moderate to significant impairment of product quality	Treatment may be required to precipitate excessive iron in effluents
> 2.0	Significant to major damage due to precipitation of iron compounds	Significant to major interference with processes	Significant to major impairment of product quality	Treatment may be required to precipitate excessive iron in effluents

Table 5.4.3: Effects of Iron on Category 3 Industrial Processes

Range of concentration (mg Fe/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 0.3 **Target Water Quality Range**	No damage due to precipitation of iron compounds	No interference with processes	No effect on product quality	No problems in waste handling
0.3 - 1.0	Minor to moderate damage due to small to precipitation of iron compounds	Negligible to minor interference with processes	Negligible to minor impairment of product quality	No problems in waste handling
1.0 - 10.0	Moderate to significant damage due to precipitation of iron compounds	Moderate to significant interference with processes	Moderate to significant impairment of product quality	Treatment may be required to precipitate excessive iron in effluents
> 10.0	Significant to major damage due to precipitation of iron compounds	Significant to major interference with processes	Significant to major impairment of product quality	Treatment may be required to precipitate excessive iron in effluents

Table 5.4.4: Effects of Iron on Category 4 Industrial Processes

Range of concentration (mg Fe/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 10.0 **Target Water Quality Range**	No or little damage due to precipitation of iron compounds	No interference with processes	No effect on product quality	No problems in waste handling
> 10.0	No serious damage arising from precipitation of iron compounds	Little interference with processes, but precipitation of iron compounds may cause blockages in pipes and nozzles	Little effect on product quality	Treatment may be required to precipitate excessive iron in effluents

5.5 Manganese

Table 5.5.1: Effects of Manganese on Category 1 Industrial Processes

Range of concentration (mg Mn/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 0.05 **Target Water Quality Range**	No damage due to precipitation of manganese compounds	No interference with processes	No effect on product quality	No problems in waste handling
0.05 - 0.2	Minor to moderate damage due to precipitation of manganese compounds	Negligible to minor interference with processes	Negligible to moderate impairment of product quality	No problems in waste handling
0.2 - 1.0	Moderate to significant damage due to precipitation of manganese compounds	Moderate to significant interference with processes	Moderate to significant impairment of product quality	Treatment may be required to reduce manganese concentrations to conform with local and General Standards for discharges
> 1.0	Significant to major damage due to precipitation of manganese compounds	Significant to major interference with processes	Significant to major impairment of product quality	Treatment required to reduce manganese concentrations to conform with local and General Standards for discharges

Table 5.5.2: Effects of Manganese on Category 2 Industrial Processes

Range of concentration (mg Mn/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 0.1 **Target Water Quality Range**	No damage due to precipitation of manganese compounds	No interference with processes	No effect on product quality	No problems in waste handling
0.1 - 0.5	Minor to moderate damage due to precipitation of manganese compounds	Negligible to minor interference with processes	Negligible to moderate impairment of product quality	Treatment may be required to reduce manganese concentrations to conform with local and General Standards for discharges
0.5 - 2.0	Moderate to significant damage due to precipitation of manganese compounds	Moderate to significant interference with processes	Moderate to significant impairment of product quality	Treatment required to reduce manganese concentrations to conform with local and General Standards for discharges
> 2.0	Significant to major damage due to precipitation of manganese compounds	Significant to major interference with processes	Significant to major impairment of product quality	Treatment required to reduce manganese concentrations to conform with local and General Standards for discharges

Table 5.5.3: Effects of Manganese on Category 3 Industrial Processes

Range of concentration (mg Mn/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 0.2 **Target Water Quality Range**	No damage due to precipitation of manganese compounds	No interference with processes	No effect on product quality	No problems in waste handling
0.2 - 1.0	Minor to moderate damage due to precipitation of manganese compounds	Negligible to minor interference with processes	Minor to moderate impairment of product quality	Treatment may be required to reduce manganese concentrations to conform with local and General standards for discharges
1.0 - 10.0	Moderate to significant damage due to precipitation of manganese compounds	Moderate to significant interference with processes	Moderate to significant impairment of product quality	Treatment required to reduce manganese concentrations to conform with local and General Standards for discharges
> 10.0	Significant to major damage due to precipitation of manganese compounds	Significant to major interference with processes	Significant to major impairment of product quality	Treatment required to reduce manganese concentrations to conform with local and General Standards for discharges

Table 5.5.4: Effects of Manganese on Category 4 Industrial Processes

Range of concentration (mg Mn/ℓ)	Damage to equipment and structures	Interference with processes	Product quality	Complexity of waste handling
0.0 - 10.0 **Target Water Quality Range**	No or little damage due to precipitation of manganese compounds	No interference with processes	No effect on product quality	Treatment to conform to General Standard only required when manganese concentrations in
> 10.0	No serious damage arising from precipitation of manganese compounds	Little interference with processes, but precipitation of manganese compounds may cause blockages in pipes and nozzles	Little effect on product quality	Treatment required to reduce manganese concentrations to conform with local and General Standards for discharges