

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

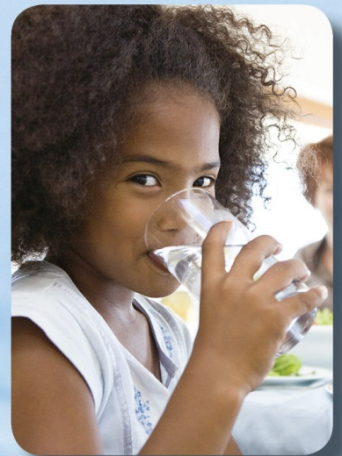
Options for the
Sustainable
Management and Use
of Residue Products
from the Treatment
of AMD

Study Report No. 5.5

P RSA 000/00/16512/5

EDITION 1

May 2013



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**.

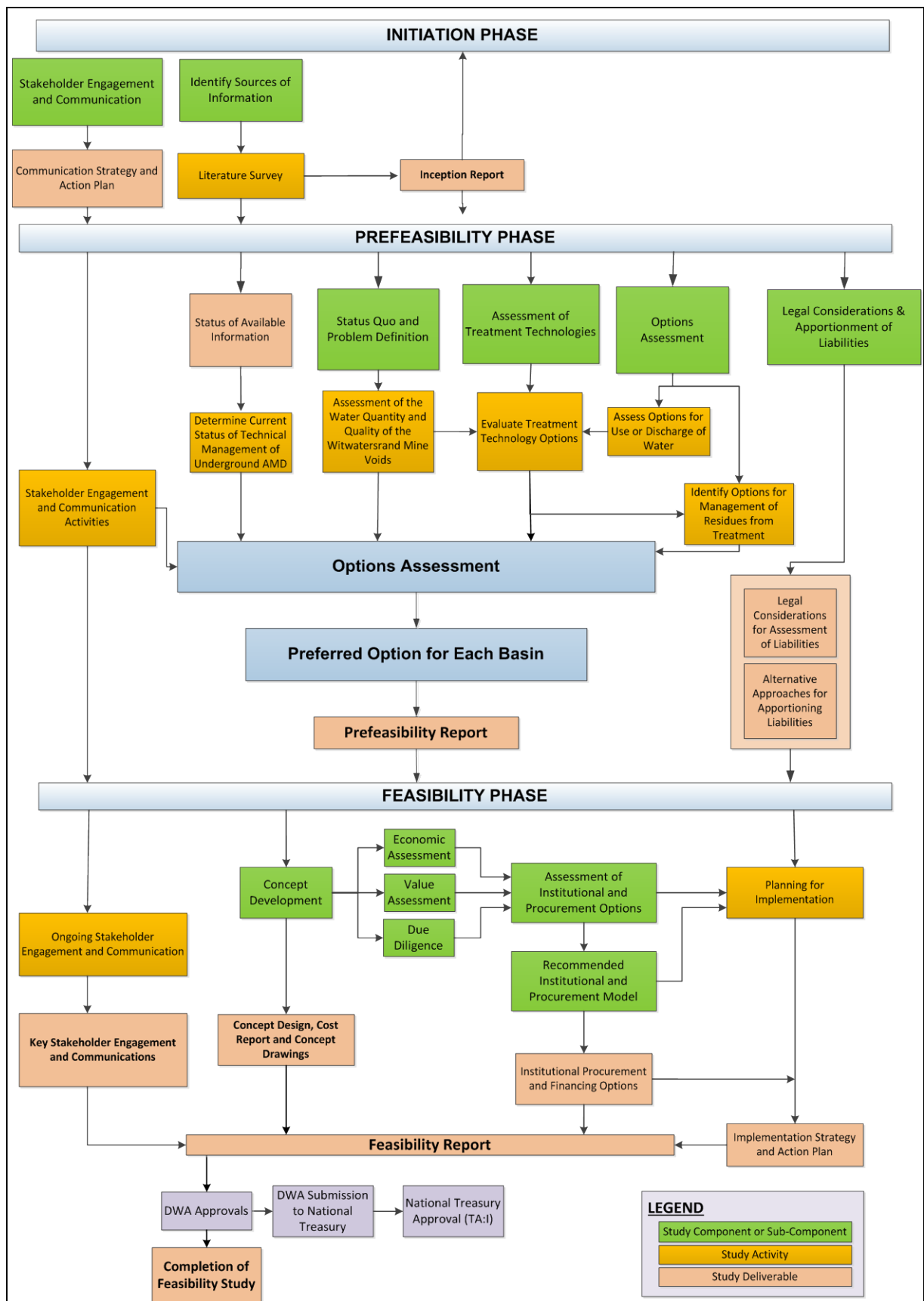


Figure 1: Study phases and components

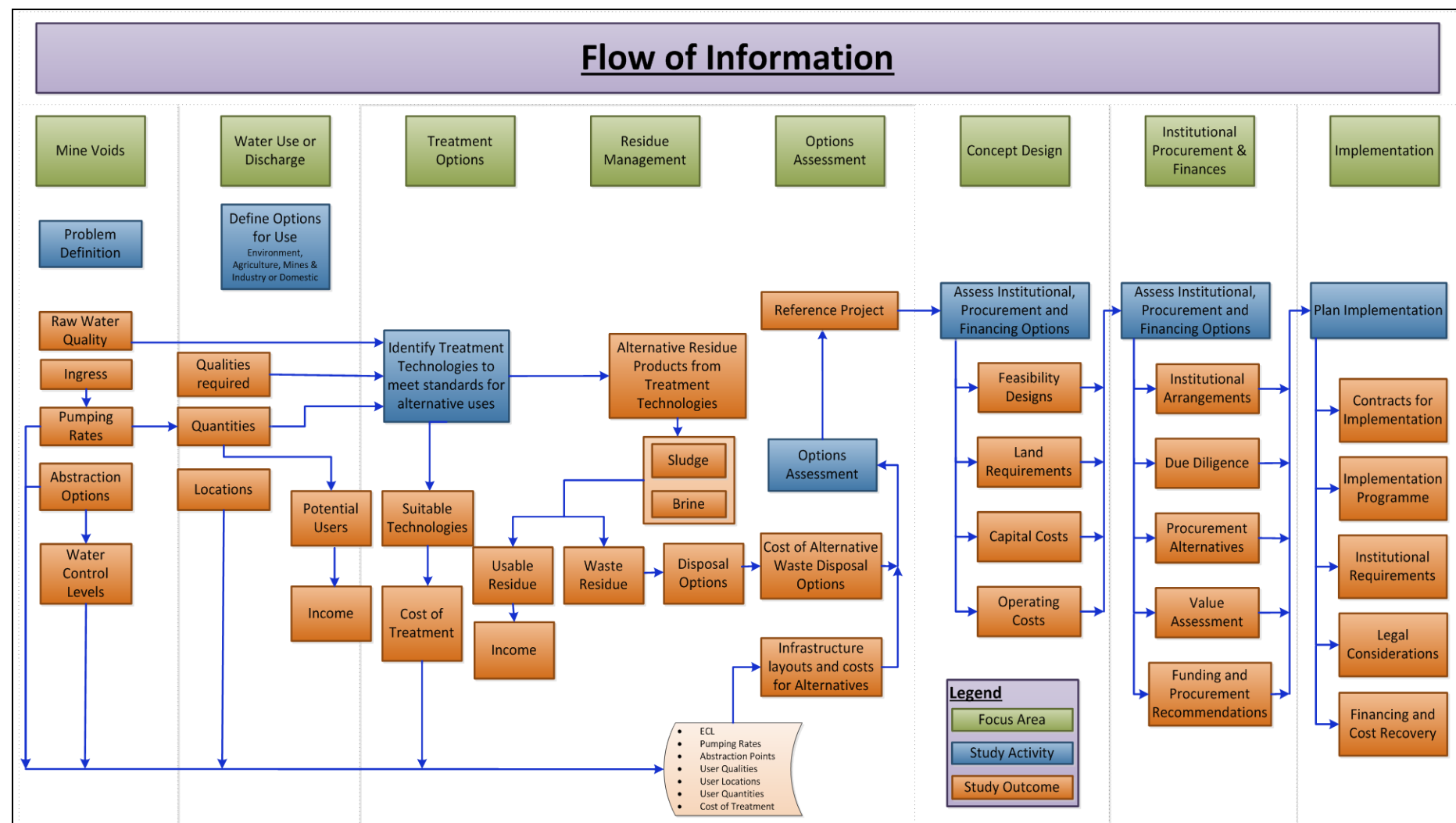


Figure 2: Flow of information throughout the Study

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 “xxvi” and “xxx” respectively.

APPROVAL

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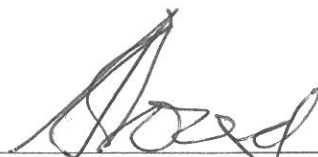
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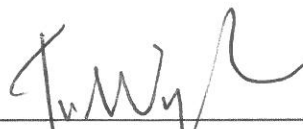


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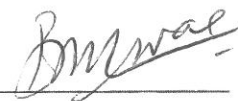
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Academic institutions;
 Funding organisations;
 Global perspectives on AMD management;
 Environmental and conservation groups;
 Independent individuals in their private capacity;
 Institutions, parastatals and research facilities;
 Local, provincial and national government;
 Mining sector;
 Non-governmental organisations;
 Organised agriculture;
 Organised business, industry and labour;
 Other specialist fields/consultants;
 Tourism and recreation;
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EXECUTIVE SUMMARY

This report deals with the conceptual siting and costing of waste disposal options for the long-term AMD treatment Reference Project. The waste from the Reference Project is considered to be classified as general waste. The waste classification can however only be finalised once the feasibility study has commenced, the treatment technologies have been confirmed and samples of the expected wastes have been received and tested.

A short-term intervention is underway, and the waste management aspects from these are considered in this report in view of the impacts of these on the long-term options as well as the possibility to incorporate these disposal methods for the long-term solution.

The long-term project is considered for a 50 year lifespan as stated in the basis of design for this conceptual study.

The Reference Project is based on the disposal of HDS sludges and brines arising from the AMD treatment plants.

Various potential sites were identified for each long-term AMD treatment plant. A desk-top study and site selection was conducted at each site. This involved identifying sites for each basin in close proximity to the treatment works. These sites were evaluated according to the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998), and the most suitable sites (or the least undesirable as the case may be) were selected. For the Western Basin two possible residue disposal facility locations were investigated namely; Western Basin and Western Basin Tunnel site. At the Central Basin three possible residue disposal facility locations were investigated namely; Central Basin, Central Basin Tunnel: Option 1 and Central Basin Tunnel: Option 2.

Waste facilities on these sites would be developed over time using downstream wall raising methods. Downstream wall raising is necessary as the HDS sludge considered in the analysis is known to be incapable of being used to build its own impoundment walls. Waste rock is considered for the wall building material as large quantities of this appears to be readily available nearby each water treatment plant.

For each selected residue disposal facility option, considering geometric constraints, an optimum area to height relationship was developed for the expected sludge quantities. Conceptual level sizing as well as capital, operating and closure costs were determined. A summary of the conceptual level sizing and cost estimates is provided in Table 1 below.

Table 1: Summary of sizing and cost estimates

Parameter	Western Basin	Western Basin Tunnel	Central Basin	Central Basin Tunnel: Option 1	Central Basin Tunnel: Option 2	Eastern Basin
<i>Final perimeter length</i>	800 m	1 090 m	1 090 m	1 090 m	1 090 m	938 m
<i>Final perimeter width</i>	660 m	665 m	665 m	665 m	665 m	613 m
<i>Final height</i>	10 m	10 m	10 m	10 m	10 m	14 m
<i>Capacity</i>	2.6 M m ³	2.6 M m ³	3.9 M m ³	3.9 M m ³	3.9 M m ³	3.5 M m ³
<i>Capital costs</i>	R 282 Million	R 344 Million	R 398 Million	R 398 Million	R 399 Million	R 278 Million
<i>Operational cost/year</i>	R 11.8 Million	R 14.1 Million	R 14.4 Million	R 14.4 Million	R 16.7 Million	R 15.6 Million
<i>Total operational costs over life</i>	R 530 Million	R 635 Million	R 650 Million	R 650 Million	R 750 Million	R 700 Million
<i>Closure costs</i>	R 65 Million	R 65 Million	R 67 Million	R 67 Million	R 67 Million	R 71 Million
<i>Total Costs</i>	R 877 Million	R 1 044 Million	R 1 115 Million	R 1 115 Million	R 1 216 Million	R 1 049 Million

Note: Although some of the facilities sizes are similar, the costs differ because of different haul distances for the waste rock. The waste rock is used for the construction and raising of the impoundment walls of the facilities.

Due to the onerous long-term management of the HDS landfill sites, as well as the extra cost and environmental burdens there is a strong case for considering alternative treatment options that do not create such quantities of waste, preferably those options that could create saleable products during the feasibility stage of the project, or which would remove contaminants which would cause the waste to be classified as hazardous.

The report also discusses the implications if the waste is classified as hazardous. This depends on the final treatment option chosen. A reclassification could rule out some options to investigate alternative disposal methods such as underground disposal, certain sites considered could be excluded. There will also be a longer term care requirements. Public resistance during the permitting phase of the hazardous landfill(s) may also be more vociferous.

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Annexures

Annexure A: Minimum Requirements for Waste Disposal by Landfill Section 4

LIST OF ACRONYMS

ABC	Alkali-Barium-Calcium
Alk	Alkalinity
AMD	Acid mine drainage
BKS	BKS Group (Pty) Ltd
BRI	Black Reef Incline
CAPEX	Capital expenditure
CB	Central Basin
CGS	Council for Geoscience
COD	Chemical Oxygen Demand
COO	Chief Operations Officer
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific Industrial Research Organisation
CSTR	Continuous stirred-tank reactor
DMR	Department of Mineral Resources
DO	Dissolved oxygen
DS	Dry solids
DST	Department of Science and Technology
DWA	Department of Water Affairs
EB	Eastern Basin
EC	Electrical conductivity
ECL	Environmental critical level
ERWAT	East Rand Water Care Company
FBR	Fluid bed reactor
GARD	Global Acid Rock Drainage
GDARD	Gauteng Department of Agriculture and Rural Development
HDS	High Density Sludge
IMC	Inter-Ministerial Committee
INAP	International Network for Acid Prevention
LTS	Long-term solution
Mintek	Council for Mineral Technology
N/A	Not applicable
NDA	Non-disclosure agreement
NECSA	South African Nuclear Energy Corporation
NEDLAC	National Economic Development and Labour Council
NGO	Non-governmental organisation
NS	Not specified
NWA (36:1998)	National Water Act, 1998 (Act No. 36 of 1998)
NWSSS	New World Sanitation & Solar Solutions
OPEX	Operating expenditure
P2W	Pollution to Water
PPP	Public-private Partnership
RO	Reverse osmosis
RWQO	Resource water quality objective
RSA	Republic of South Africa
SAC	Study Administration Committee
SALGA	South African Local Government Association

SANS	South African National Standards
SMC	Study Management Committee
SRB	Sulphate reducing bacteria
SRK	SRK Consulting (Pty) Ltd
SSC	Study Stakeholder Committee
STI	Short-term intervention
TA 1	Treasury Approval 1
TCTA	Trans-Caledon Tunnel Authority
TDS	Total dissolved solids
TIA	Technology Innovation Agency
TRL	Technology Readiness Level
TRU	Thermal Recovery Unit
TUT	Tshwane University of Technology
UK	United Kingdom
WB	Western Basin
WRC	Water Research Commission
WUC	Western Utilities Corporation
WWTW	Wastewater treatment works

LIST OF CHEMICAL CONSTITUENTS

Al	Aluminium
Al(OH) ₃	Aluminium hydroxide
Ca	Calcium
Ca(OH) ₂	Calcium hydroxide (slaked lime)
Ca ₃ (PO ₄) ₂	Calcium phosphate
CaCO ₃	Calcium carbonate (limestone)
CaF ₂	Calcium fluoride
CaSO ₄	Gypsum
Cl	Chloride
Fe	Iron
Fe(OH) ₂	Iron(II) hydroxide
Fe(OH) ₃	Iron(III) hydroxide (ferric hydroxide)
Mg	Magnesium
Mg(OH) ₂	Magnesium hydroxide
Mn	Manganese
Mn(OH) ₂	Manganese hydroxide
Na	Sodium
SO ₄	Sulphate
SO ₄ ²⁻	Sulphate ion
U	Uranium

UNITS OF MEASUREMENT

~	approximately
µg	microgram
µS	microsiemen
C	Celsius
cm	centimetre
d	day
ha	hectare
h	hour
kW	kilowatt
kWh	kilowatt hour
ℓ	litre
m	metre
m ³	cubic metre
mg	milligram
Mℓ	megalitre
mS	millisiemen
R	Rand
t	ton

GLOSSARY OF TERMS

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.
Amphoteric	A molecule or ion that can react as an acid as well as a base.
Central Basin	Central Rand underground mining basin.
Claus process	A gas desulphurising process that recovers elemental sulphur from gaseous hydrogen sulphide.
Decant (in mining)	Uncontrolled discharge or seepage of mine water at the surface.
Discharge	Discharge of mine water from mine-workings to the environment.
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, in order to protect specific environmental features, including groundwater resources.
Ettringite	A hydrous calcium aluminium sulphate mineral.
Feasibility study	An analysis and evaluation of a proposed project to determine if it is technically sound, socially acceptable and economically and environmentally sustainable.
GARD Guide	The Global Acid Rock Drainage (GARD) Guide is sponsored by the International Network for Acid Prevention (INAP) with the support of the Global Alliance. The GARD Guide deals with the prediction, prevention and management of drainage produced from sulphide mineral oxidation, often termed 'acid rock drainage'. It also addresses metal leaching caused by sulphide mineral oxidation. It is intended as a state-of-the-art summary of the best practices and technology to assist mine operators and regulators to address issues related to sulphide mineral oxidation.
Groundwater	Water occupying openings below ground.
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 national, provincial and local and district government, NGOs, organised business, mining, industry, labour, agriculture, affected mines, affected water utilities, community leaders, academics, etc.).
Long-term solution	A solution that is sustainable in the long-term with regard to the technical, legal, economic, financial and institutional aspects.

Option	One of a number of combinations of abstraction works, treatment process and solutions for the disposal of waste and treated water.
Preferred option	The solution, or combination of solutions, for the three basins that will be selected for further investigation in the feasibility phase and if found feasible, that would eventually be recommended to the client.
Reef	Term used on the Witwatersrand mines for conglomerate.
SAVMIN	Treatment technology developed by Mintek and proposed by Veolia Water.
Scenario	An alternative projection of the macro environment that affects AMD, such as climate change, electricity load-shedding and changes in the quality or quantity of water ingress to the mine void.
Short-term interventions (short-term solution as stated in Terms of Reference)	Measures that are being implemented in the short-term while the long-term feasibility study for LTS is undertaken.
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 Gold Reef City museum and active or planned mining.
Stakeholder	A person, group or community who has an interest in or is affected by AMD and the feasibility study to address the problem.
Western Basin	West Rand underground mining basin.

1 INTRODUCTION

1.1 Aims and Objectives of this Report

The purpose of this report is to assess and evaluate options available for the disposal of residues expected from the treatment of Acid Mine Drainage (AMD), for incorporation into the Long-Term Solution (LTS) for the management of AMD. It also considers the options in the case that the wastes are classified as hazardous waste. It also considers the wastes generated from alternative treatment technologies.

1.2 Structure of Report

This report is structured to:

- describe the various AMD treatment options considered;
- describe the residue quantities and qualities expected from the treatment options which is recommended for the Reference Project;
- define the Reference Project on which the disposal options and costs are considered;
- discuss the existing short-term disposal options in the context of these being potential options for long-term waste disposal;
- itemise the Reference Project disposal options for each proposed treatment plant together with a conceptual siting and design of the disposal facilities;
- consider options for brine handling; and
- provide the conceptual level costs of the preferred disposal site for each treatment plant location.
- discuss the implications if the residues are classified as hazardous wastes instead of general wastes;

This report forms part of the Prefeasibility investigation and feeds into the DWA AMD FS 2013, Study Report No. 5: “**Technical Prefeasibility Report**” together with Study Reports Nos. 5.1 to 5.4. The preferred options for each basin which are recommended in these reports are investigated in more detail in the Feasibility investigation (DWA AMD FS 2013, Study Reports Nos. 6, 6.1 and 6.2).

2 SUMMARY OF AMD TREATMENT TECHNOLOGIES

2.1 Evaluation Criteria

This section provides a brief overview of the technologies that was evaluated in DWA AMD FS 2013, Study Report No. 5.4: “**Treatment Technology Options**”.

The following criteria were selected as a guideline for the evaluation of pre-treatment and primary treatment technologies presented by prospective service providers, focussing on various aspects of the management and use of residue products from the treatment of AMD:

- Quality of the feed water that can be treated with the technology;
- Quality of the treated water that can be achieved through the process;
- Chemicals used in the technology;
- Residue products produced;
- Requirements for the disposal of the waste products;
- State of development of the technology;
- Complexity of the process; and
- Risks associated with the technology:
 - Variations in the volume to be treated;
 - Variations in the quality of the AMD to be treated;
 - Health risks;
 - Environmental risks; and
 - Potential failure.

Figure 2.1 illustrates what water quality (i.e. raw or pre-treated) feeds into what process (i.e. Pre-treatment or Primary Treatment).

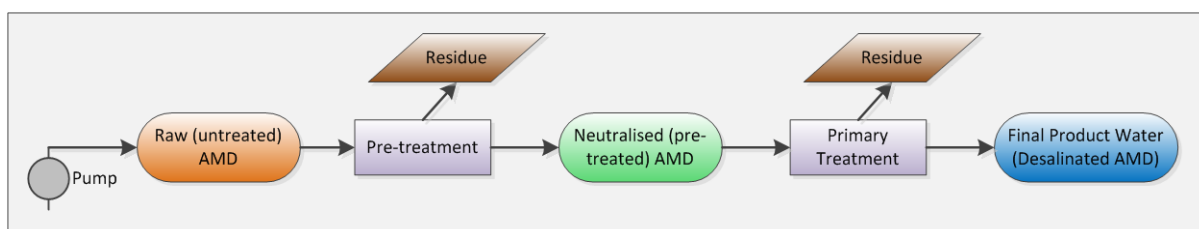


Figure 2.1: Feed water quality and treatment process terms

The costs of the various technologies will be evaluated using a comprehensive approach to ascertain the total costs, including the cost of disposing of the residue products, as well as the potential income from selling the water or some of the residue products.

In any final selection or tender process, additional criteria would be considered, including local representation and support, as well as local manufacture.

2.2 Evaluation of Technologies

2.2.1 Pre-treatment Technologies

a) Quality of the Raw AMD that can be treated with the technology

The comparison of the pre-treatment technologies in respect of the quality of raw AMD that can be treated is summarised in **Table 2.1** below.

Table 2.1: Comparison of pre-treatment technologies in respect of the quality of raw AMD that can be treated.

Technology	Supplier	Quality of raw water	Comments
HDS	Process technology is held by various suppliers.	Process can be adjusted to variable situations with relative ease.	Suitable process-control instrumentation needs to be provided to ensure that the plant is operated at optimal conditions.
Fe-CN process	Mintails is the sole supplier.	Acidity and Fe concentrations need to be carefully balanced with the cyanide concentration in the gold processing waste to be treated.	Process-control instrumentation is of utmost importance to ensure that the process is operated correctly.

The HDS process has more flexibility to adapt to variations in the quality of raw AMD that can be treated and would thus be recommended for further consideration instead of the Fe-CN process.

b) Quality of the neutralised (pre-treated) AMD that can be achieved through the process

The comparison of the pre-treatment technologies in respect of the quality of neutralised AMD that can be produced is summarised in **Table 2.2** below.

Table 2.2: Comparison of pre-treatment technologies in respect of quality of pre-treated AMD.

Technology	Supplier	Quality of neutralised AMD	Comments
HDS	Process technology is held by various suppliers.	Fe < 1.0 mg/l pH > 8.1 Mn concentration depends on pH of operation. SO ₄ < 2 400 mg/l No change in monovalent ions.	The concentrations of various components will vary in accordance with the variation in the raw feed that has to be treated. Monitoring and process control are important for all three basins.

Technology	Supplier	Quality of neutralised AMD	Comments
Fe-CN process	Mintails is the sole supplier.	<p>Fe < 1.0 mg/l</p> <p>pH > 7.5</p> <p>No change in monovalent ions.</p> <p>Possible increase in uranium concentration.</p> <p>No information on possible heavy metals.</p> <p>Quality of neutralised AMD to be proven.</p>	<p>This process is new and no data is available at this stage.</p> <p>Possibility of cyanide contamination if process operated outside design parameters.</p>

Insufficient information was available on the Fe-CN process and the quality of the treated water must still be proved, thus the HDS process is recommended for the Reference Project.

c) Chemicals Used in the Technology

The comparison of the pre-treatment technologies in respect of the chemicals used is summarised in **Table 2.3** below.

Table 2.3: Comparison of pre-treatment technologies in respect of chemicals used

Technology	Chemicals	Quantities used (t/d)	Comments
HDS	<p>Limestone (CaCO_3)</p> <p>Western Basin:</p> <p>Central Basin:</p> <p>Eastern Basin:</p> <p>Slaked lime (Ca(OH)_2)</p> <p>Western Basin:</p> <p>Central Basin:</p> <p>Eastern Basin:</p> <p>Oxygen</p>	<p>73</p> <p>89</p> <p>0</p> <p>25</p> <p>14</p> <p>41</p>	None.
Fe-CN process	<p>Chemicals used in gold recovery process:</p> <ul style="list-style-type: none"> Cyanide Lime 	Quantities unknown.	Cyanide is poisonous, and experienced operators are required to operate the process.

d) Residue Products Produced

The comparison of the pre-treatment technologies in respect of the residue produced based on the feed water quality at the 95th percentile is summarised in **Table 2.4** below.

Table 2.4: Comparison of pre-treatment technologies in respect of wastes produced.

Technology	Waste product	Quantities produced (t DS/Mℓ)*	Comments
HDS	Sludge, being a mixture of metal hydroxides and gypsum. Western Basin: Central Basin: Eastern Basin:	 5.5 6.1 1.9	The sludge is of a quality that cannot be used beneficially. It will contain uranium and therefore has to be classified as a hazardous waste.
Fe-CN process	Sludge in the form of an Fe-CN complex.	The quantity of sludge is not known at this stage.	The sludge is classified as a hazardous sludge. It is co-disposed with the spent tailings from the gold recovery process.

* DS – Dry Sludge

Insufficient information was provided on the wastes produced by the Fe-CN process to allow a detailed comparison between the two pre-treatment technologies, therefore the HDS process is recommended for the Reference Project as far as the waste products are concerned.

e) Requirements for the Disposal of the Waste Products

The comparison of the pre-treatment technologies in respect of the disposal of the wastes produced is summarised in **Table 2.5** below.

Table 2.5: Comparison of pre-treatment technologies in respect of the disposal of waste products.

Technology	Waste product	Disposal method	Comments
HDS	Metal hydroxide/Gypsum sludge	Disposal in a purpose-designed sludge-disposal facility. Needs to comply with standards of hazardous waste landfills.	Sludge is classified as hazardous due to the possible heavy metal content and the known content of uranium.
Fe-CN process	Sludge with Fe-CN complex	Co-disposal with spent tailings from gold recovery process.	Disposal site needs to meet the specifications applicable to mining wastes.

Since the waste products from both pre-treatment processes will be classified as hazardous, but the quantity of waste from the Fe-CN process is not known, the HDS process is recommended from a waste disposal perspective for the Reference Project.

f) State of Development of the Technology

The comparison of the pre-treatment technologies in respect of the state of development of the technology is summarised in **Table 2.6** below.

Table 2.6: Comparison of pre-treatment technologies in respect of the state of development of the technology.

Technology	Supplier	State of development	Comments
HDS	Process technology is held by various suppliers.	The technology is proven (i.e. TRL* = 9).	Well-known technology, with various suppliers being able to implement large-scale installations.
Fe-CN process	Mintails is the sole supplier.	The technology is new and considered to be in the pilot stage (i.e. TRL = 4).	Mintails, the owner of the technology, is in the process of installing a large-scale pilot plant at the Mogale Gold Mine at their own cost. Results of the installation will be monitored closely.

* TRL – Technology Readiness Level

A technology with a TRL of 9, which is the highest level of development, has the lowest risk associated with it. For this reason, the HDS process, with a TRL of 9, is recommended for further consideration, rather than the Fe-CN process with a TRL of 4.

g) Complexity of the Process

The evaluation of technology in respect of its complexity is a subjective process, but in this instance the endeavour is to differentiate between processes and to highlight the differences between the technologies. The comparison of the pre-treatment technologies in respect of the complexity of the process is summarised in **Table 2.7** below.

Table 2.7: Comparison of pre-treatment technologies in respect of the complexity of the process.

Technology	Supplier	Complexity of technology	Comments
HDS	Process technology is held by various suppliers.	Low to medium complexity.	The technology is well known. Complications are still being experienced with precipitation in structures and pipelines. Requires good control of maintenance.

Fe-CN process	Mintails is the sole supplier.	Medium	<p>Technology is not known, although mines have experience of handling and working with cyanide.</p> <p>Very good and stringent process control is required.</p> <p>The maintenance of control instruments is highly important.</p> <p>Well-trained operators are required.</p>
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Based on the information available, the HDS process appears to be less complex than the Fe-CN process and would thus be recommended for further consideration.

h) Risks Associated with the Technology

The comparison of the pre-treatment technologies in respect of the associated risks is summarised in **Table 2.8** below.

Table 2.8: Comparison of pre-treatment technologies in respect of the associated risks.

Technology	Risks in respect of variations		Health risks	Environmental risks	Risk to failure
	Volume to be treated	Quality of raw AMD			
HDS	Low risk in terms of the volume that can be treated; plant can be designed to whatever volume has to be treated.	Quantity of chemicals used is in direct relation to the chemical composition of the AMD. Plant can be designed to treat any chemical composition.	Low risk: simple personal protective equipment required mainly to protect against lime dust.	Low risk to environment; no dangerous chemicals are used in the process.	Medium risk of equipment failure as a result of chemical blockages (precipitates).
Fe-CN process	Volume that can be treated is dependent on the production of the gold recovery plant. There would typically be oversupply of one stream and undersupply of another – this means that either there will not	Acidity of AMD and Fe concentration need to be balanced with the cyanide concentration in the gold recovery wastewater. Variable waste streams increase the complexity of the process.	High risk: cyanide is extremely poisonous. Operation needs to be closely controlled.	High risk: at failure, cyanide can be released to the environment as a gas or in solution. Mines have experience of operations using cyanide.	Medium risk: it is important that the balance between the waste streams is maintained. Detailed risk assessments will be required to assess the risks posed by gold plant maintenance shuts or variations in the gold price.

Technology	Risks in respect of variations		Health risks	Environmental risks	Risk to failure
	Volume to be treated	Quality of raw AMD			
	be sufficient gold plant flow or there won't be sufficient AMD, requiring that capacity to treat whatever stream is in excess will still be required.				

Taking into consideration all of the above criteria in the evaluation of the pre-treatment technologies, the HDS process is recommended for further consideration during the Feasibility phase.

It is important to note that the concentration of uranium in the AMD exceeds the SANS-241 (2011) limit by several factors, even at the 50th percentile. Special treatment processes will be required to reduce this to the SANS-241 requirements. Refer to DWA AMD FS 2013, Study Report No. 5.4: “**Treatment Technology Options**” for background on the Ion Exchange process which is capable of removing the uranium in AMD. It is suggested that allowance be made for Ion Exchange to be included before the HDS plant in the Reference Project.

2.2.2 Treatment Technologies for Primary Treatment (desalination) of AMD

a) Quality of the feed water (i.e. pre-treated AMD) that can be treated with the technology

The comparison of the treatment technologies for desalination of AMD in respect of the quality of feed water (pre-treated AMD) that can be treated is summarised in **Table 2.9** below.

Table 2.9: Comparison of treatment technologies for desalination of AMD in respect of the quality of the feed water that can be treated.

Technology	Supplier	Quality of feed water	Comments
Conventional RO	Numerous suppliers available.	Technology requires pre-treatment with HDS. Technology requires that Fe and Mn concentrations are low.	Fe and Mn become a problem at relatively low concentrations in that the life of the membranes is reduced, thus increasing the costs of the operation. If the pre-treatment is done within the specifications, the technology

Technology	Supplier	Quality of feed water	Comments
			can accommodate any neutralised AMD.
Alternative RO	MiWaTek	No pre-treatment other than pH adjustment is required. The supplier states that only the pH needs to be controlled at ± 4.0 .	The process is not well known. A pilot plant is under construction at Shaft No 8 to prove the technology.
Electrocoagulation	P2W	Technology requires pre-treatment with HDS. The supplier states that the technology can be adapted to meet any demands.	The supplier has not divulged the principles of the technology as this is considered to be their intellectual property; it is therefore not possible to comment.
ABC process	Western Utilities Corporation	Technology requires pre-treatment with HDS. Lower concentrations of SO_4 may impede the viability and efficiency of the process.	HDS needs to be operated at a pH of 11.0 to remove Mg.
SAVMIN	Veolia/Mintek	Technology requires pre-treatment with HDS.	HDS needs to be operated at a pH of 11.0 to remove Mg .
Biosure	ERWAT	Technology requires pre-treatment with HDS. Demand on carbon source in relation to the SO_4 concentration.	None.
Biological sulphate reduction	Paques	Technology requires pre-treatment with HDS. Demand on carbon source in relation to the SO_4 concentration.	None.

The Alternative RO by MiWaTek has potential for use in the future, since no pre-treatment besides pH adjustment is required. However, this process has not been proven yet and therefore conventional RO is recommended for the Reference Project if the quality of the feed water is considered.

b) Quality of the desalinated AMD that can be achieved through the process

The comparison of the treatment technologies for desalination of AMD in respect of the quality of desalinated AMD that can be produced is summarised in **Table 2.10**.

Table 2.10: Comparison of treatment technologies for desalination of AMD in respect of the quality of desalinated AMD that can be produced.

Technology	Supplier	Quality of desalinated AMD	Comments
Conventional RO	Numerous suppliers available	Any specification can be met. Can remove uranium from final product.	The production of brine is dependent on the specifications of the desalinated water. Uranium will be concentrated in the brine.
Alternative RO	MiWaTek	Any specification can be met. Can remove uranium from final product.	The production of brine is dependent on the specifications of the desalinated water. Uranium will be concentrated in the brine.
Electrocoagulation	P2W	Process does not remove monovalent ions or uranium. Specifications are unlikely to be met without further treatment.	Further processes, such as RO, may be required if the monovalent ions exceed the specifications. The removal of uranium from the final product may require additional processes.
ABC process	Western Utilities Corporation	Process does not remove monovalent ions or uranium. Specifications are unlikely to be met without further treatment Sulphate concentration is maintained at 200 mg/l.	Further processes, such as RO, may be required if the monovalent ions exceed the specifications. A safety margin is required to prevent the release of soluble barium to the final product. The removal of uranium from the final product may require additional processes.
SAVMIN	Veolia/Mintek	Process does not remove monovalent ions or uranium. Specifications are unlikely to be met without further treatment.	Further processes, such as RO, may be required if the monovalent ions exceed the specifications. The removal of uranium from the final product may require additional processes.
Biosure	ERWAT	Process does not remove monovalent ions or uranium. Specifications are unlikely to be met without further treatment.	Further processes, such as RO, may be required if the monovalent ions exceed the specifications. The removal of uranium from the final product may require additional processes.
Biological sulphate reduction	Paques	Process does not remove monovalent ions or uranium. Specifications are unlikely to be met without further treatment.	Further processes, such as RO, may be required if the monovalent ions exceed the specifications. The removal of uranium from the final product may require additional processes.

The Conventional and Alternative RO processes are the only processes that can meet the specifications of any of the potential users (refer to DWA AMD FS 2013, Study Report No. 5.3: “Options for Use or Discharge of Water”). On this basis only these two processes would be recommended for inclusion in the Reference Project.

c) Chemicals Used by the Technology

The comparison of the treatment technologies for desalination of AMD in respect of the chemicals used is summarised in **Table 2.11** below. The values quoted are based on the feed water quality at the 95th percentile.

Table 2.11: Comparison of treatment technologies for desalination of AMD in respect of the chemicals used.

Technology	Chemicals	Quantities used (t/d)			Comments
		Western Basin	Central Basin	Eastern Basin	
Conventional RO	Sulphuric acid	12.2	24.5	34.5	See Tables 2.9 and 2.10. These quantities were estimated by the study team.
	Coagulant	1.9	4.3	5.3	
	Disinfectant	11.3	21.5	37.0	
	Caustic soda	7.3	6.0	5.7	
	SMBS	12.4	26.1	36.9	
	Anti-scalant	10.9	27.1	22.7	
	Lime	418.9	1098.5	1473.8	
Alternative RO	Sulphuric acid	-	-	-	It is expected that similar chemicals will be used for the cleaning of the membranes and the precipitation of the sulphate. Quantities are not available at this stage.
	Coagulant	-	-	-	
	Disinfectant	-	-	-	
	Caustic soda	-	-	-	
	SMBS	-	-	-	
	Anti-scalant	-	-	-	
	Lime	-	-	-	
Electrocoagulation	Chemical consumption unknown.	-	-	-	Quantities are unknown.
ABC process	Lime	-	-	-	Quantities are unknown for the different basins.
	Barium sulphate	-	-	-	
	Carbon/coal	-	-	-	
	Oxygen/air	-	-	-	
SAVMIN	Lime	-	-	-	Quantities are unknown.
	Aluminium sulphate	-	-	-	
	Sulphuric acid	-	-	-	
	Aluminium hydroxide	-	-	-	
	Carbon dioxide	-	-	-	
Biosure	Biodegradable	-	-	-	2 kg biomass per kg of

Technology	Chemicals	Quantities used (t/d)			Comments
		Western Basin	Central Basin	Eastern Basin	
	substances such as high organic waste.				sulphate removed.
Biological sulphate reduction	Biodegradable substances such as high organic waste. Hydrogen	-	-	-	Quantities are not known.

Not enough information was available on any of the alternative primary treatment technologies to allow an informed evaluation of the technologies with regards to the chemicals used in the treatment processes.

d) Residue Products Produced

The comparison of the treatment technologies for desalination of AMD in respect of the residues produced is summarised in **Table 2.12** below. The values quoted are based in the feed water quality at the 95th percentile.

Table 2.12: Comparison of treatment technologies for desalination of AMD in respect of residues produced.

Technology	Residue product	Quantities produced			Comments
		Western Basin	Central Basin	Eastern Basin	
Conventional RO	Gypsum sludge (t DS/d) Brine (kl/d)	40.8 115	163.7 0	242.7 0	The production of brine is dependent on the quality of the raw AMD and the specifications for the treated water.
Alternative RO	Metal hydroxide sludge Gypsum sludge (t DS/d) Brine (kl/d)	No data available.			None.
Electrocoagulation	Gypsum sludge	No data available.			None.
ABC process	Elemental sulphur Lime	No data available.			Lime can be used to reduce the requirements for lime in the HDS process.
SAVMIN	Gypsum	No data available.			None.
Biosure	Metal sulphides or Biosulphur Biological sludge	No data available.			None.

Technology	Residue product	Quantities produced			Comments
		Western Basin	Central Basin	Eastern Basin	
Biological sulphate reduction	Biosulphur Biological sludge	No data available.			None.

Not enough information was available on any of the alternative primary treatment technologies to allow an informed evaluation of the technologies with regards to the chemicals used in the treatment processes.

e) Requirements for the Disposal of the Residues Products

The comparison of the treatment technologies for desalination of AMD in respect of the disposal of the residues produced is summarised in **Table 2.13** below.

Table 2.13: Comparison of treatment technologies for desalination of AMD in respect of the disposal of residues.

Technology	Residue product	Disposal method	Comments
Conventional RO	Gypsum sludge (t DS/d) Brine (kl/d)	Gypsum sludge may be used beneficially in the cement industry. Brine goes to evaporation ponds.	There is currently an oversupply of gypsum in the country and hence the market value of the product is very low. The brine consists of a mixture of salts, hence it would be costly to remove certain salts selectively.
Alternative RO	Metal hydroxide sludge Gypsum sludge (t DS/d) Brine (kl/d)	The supplier states that there is interest in the metal hydroxides. Gypsum sludge may be used beneficially in the cement industry. Brine goes to evaporation ponds.	There is currently an oversupply of gypsum in the country and hence the market value of the product is very low. The brine consists of a mixture of salts, hence it would be costly to remove certain salts selectively.
Electrocoagulation	Gypsum sludge	Gypsum sludge may be used beneficially in the cement industry.	None.
ABC process	Elemental sulphur Lime	Elemental sulphur can be sold at market value. The lime can be used in the HDS process upstream of the ABC process.	None.

Technology	Residue product	Disposal method	Comments
SAVMIN	Gypsum	Gypsum sludge may be used beneficially in the cement industry.	None.
Biosure	Metal sulphides or Biosulphur Biological sludge	Metal sulphides need disposal on special waste disposal sites. Elemental sulphur can be sold at market value. Biological sludge can be disposed in the same way as the sludge from Wastewater Treatment Works.	Metal sulphides are considered a pollutant, as the sulphides will be oxidised in the atmosphere to generate surface 'AMD'. The process for biologically converting sulphide to elemental sulphur has not been finalised (TRL = 4); alternatively, the SULFATEQ™ process should be implemented (Paques patent).
Biological sulphate reduction	Biosulphur Biological sludge	Elemental sulphur can be sold at market value. Biological sludge can be disposed of in the same way as the sludge from wastewater treatment works.	None.

All technologies have the potential to produce residue products which can be sold as commercial products. However, there is an oversupply of gypsum in the country and therefore the production of other usable residue products will be advantageous.

f) State of Development of the Technology

The comparison of the treatment technologies for desalination of AMD in respect of their state of development is summarised in **Table 2.14** below.

Table 2.14: Comparison treatment technologies for desalination of AMD in respect of their state of development.

Technology	Supplier	State of Development	Comments
Conventional RO	Numerous suppliers available	Technology is proven (TRL = 9).	The technology has a wide application. There are several large installations in South Africa..
Alternative RO	MiWaTek	Technology is in pilot plant stage (TRL = 6).	Pilot testing is currently under way.
Electro-coagulation	P2W	Technology has not been used in South Africa, but installations of comparable size are being provided in Ghana (TRL = 8).	Installations in other parts of the world need to be investigated (e.g. Ghana).

Technology	Supplier	State of Development	Comments
ABC Process	Western Utilities Corporation	Technology is considered to be in the pilot plant stage (TRL = 5).	Elements of the process have been tested in relatively small pilot plants.
SAVMIN	Veolia/Mintek	Technology is considered to be in the pilot plant stage (TRL = 5).	
Biosure	ERWAT	Technology is considered to be in the pilot plant stage (TRL = 8).	The production of biosulphur has not been tested adequately. Experiments are being conducted to find alternative sources for biomass.
Biological Sulphate Reduction	Paques	Technology has been applied abroad, but not at the capacity required in South Africa (TRL = 7).	This process has been installed elsewhere, but not at the scale required in this instance.

Conventional RO is the only technology with a TRL of 9 (lowest risk) and should be recommended for the Reference Project on this basis. However, several of the alternative, innovative technologies have fairly high TRL's and should be considered for implementation as pilot plants to prove themselves for possible implementation in the long-term.

g) Complexity of the Process

The comparison of the treatment technologies for neutralised AMD in respect of the complexity of the process is summarised in **Table 2.15** below. There is no scale to measure the complexity of processes and therefore the comparison was done by ranking the various technologies. Comments on the complexity can however be made.

Table 2.15: Comparison of treatment technologies for desalination of AMD in respect of the complexity of the process.

Technology	Supplier	Complexity of technology	Comments
Conventional RO	Numerous suppliers available	Medium complexity.	The technology entails a number of processes, hence requiring good knowledge of all processes and tight control on the operation.
Alternative RO	MiWaTek	Medium complexity, yet higher than conventional RO.	The technology entails the following of a number of processes, hence requiring good knowledge of all processes and tight control on the operation. It is a new technology and not all operational parameters are known and fully understood.

Technology	Supplier	Complexity of technology	Comments
Electro-coagulation	P2W	Medium, but perceived to be lower than conventional RO.	The technology appears to have less process steps than conventional RO. It is a new technology and not all operational parameters are known and fully understood.
ABC Process	Western Utilities Corporation	High	The technology has a number of highly complex processes following each other. The technology is new. The processes produce explosive, toxic and corrosive substances at a high energy level ($\pm 1\ 000^{\circ}\text{C}$). Of all the proposed technologies, this is the most complex technology. Failure of some of the processes could be catastrophic.
SAVMIN	Mintek	Medium, but higher than conventional RO.	The technology entails a number of processes, hence requiring good knowledge of all processes and tight control on the operation – more than what is required at the RO - processes. It is a new technology and not all operational parameters are known and fully understood.
Biosure	Erwat	Medium in respect of the reduction of the sulphate, however the production of bio sulphur is considered to be more complex than the reduction process.	Technology is new and not all parameters are known and fully understood, especially the production of bio sulphur.
Biological Sulphate Reduction	Paques	Medium complexity, depending on the energy source. If hydrogen is used, then the complexity is significantly increased due to the higher energy levels being applied in the technology.	The process has not been applied at the scale required, hence the complexity of the required installation could be underestimated.

Most of the treatment technologies have a medium complexity associated with it and thus, with the level of detail information available, no definite distinction could be made on this basis.

h) Risks Associated with the Technology

The comparison of the treatment technologies for desalination of AMD in respect of the associated risk is summarised in **Table 2.16** below.

Table 2.16: Comparison of technologies in respect of the associated risk.

Technology	Risks in respect of variations		Health risks	Environmental risks	Risk of failure
	Volume to treat	Quality of raw AMD			
Conventional RO	Independent of volume to be treated.	Independent of quality of raw AMD.	No significant health risks; normal personal protective equipment required.	No significant risks. No damage other than untreated AMD being released to the environment.	No catastrophic consequence of failure (except membrane replacement).
Alternative RO	Independent of volume to be treated.	Independent of quality of raw AMD.	No significant health risks; normal personal protective equipment required.	No significant risks. No damage other than untreated AMD being released to the environment.	No catastrophic consequence of failure (except membrane replacement).
Electrocoagulation	Independent of volume to be treated.	Risk not known	No significant health risks; normal personal protective equipment required.	No significant risks. No damage other than untreated AMD being released to the environment.	No catastrophic consequence of failure (except membrane replacement).
ABC Process	Technology requires large quantities to gain benefit from economies of scale.	It is perceived that higher concentrations of sulphate would benefit the process.	High risk due to the substances being used and produced (barium carbonate and hydrogen sulphide gas).	High risk due to the substances being used and produced (barium carbonate and hydrogen sulphide gas).	High risk due to the substances being used and produced (barium carbonate and hydrogen sulphide gas). Failure could have catastrophic consequences.
SAVMIN	Independent of volume to be treated.	Independent of quality of raw AMD.	No significant health risks; normal personal protective equipment	No significant risks. No damage other than untreated AMD being released	No catastrophic consequence of failure.

Technology	Risks in respect of variations		Health risks	Environmental risks	Risk of failure
	Volume to treat	Quality of raw AMD			
			required.	to the environment.	
Biosure	Independent of volume to be treated.	Independent of quality of raw AMD.	Release of Hydrogen Sulphide from process can be dangerous, but otherwise no significant health risks; normal personal protective equipment required.	No significant risks No damage other than untreated AMD being released to the environment.	No catastrophic consequence of failure.
Biological Sulphate Reduction	Independent of volume to be treated.	Independent of quality of raw AMD.	Release of Hydrogen Sulphide from process can be dangerous, but otherwise no significant health risks; normal personal protective equipment required.	No significant risks. No damage other than untreated AMD being released to the environment.	No catastrophic consequence of failure.

Taking into consideration all of the above criteria in the evaluation of the primary treatment technologies, the Conventional RO process is recommended for further consideration during the Feasibility phase.

2.3 Summary of Processes

There are various technologies that can treat the AMD-derived water to the required standards (SANS 241: 2011). Most of the processes, however, do not remove the monovalent ions from the water and hence some form of RO is required in all instances where the monovalent ions in the feed AMD exceed the target standards for the treated water. This supplementary treatment could be added with relative ease to each of the processes that do not meet the specifications. It would not be necessary to treat the full stream of AMD in the process, as it would only be necessary to remove an adequate mass of salts to meet the applicable standards. However, when adding RO onto any of the processes, a brine stream will once again be produced and brine disposal will be required.

More important, therefore, are the waste products that are produced through each of the processes, as these substances need to be used or disposed of as long as AMD from the mining basins is being abstracted and treated; extensive disposal sites would be required. It is also important that the substances formed are adequately stable so as not to potentially pollute the environment. The stability of the residue products, as well as the volumes produced, should therefore be a major criterion in the selection of the long-term treatment solution.

A further factor to be taken into account is the level of development of the technology. As stated earlier in the report, there are three levels of development according to which the technology has been classified (i.e. laboratory scale, pilot scale and proven technologies). Of all the technologies investigated, only the HDS process and the conventional RO process can be classified as proven technologies (refer to DWA AMD FS 2013, Study Report No. 5.4: **“Treatment Technology Options”**). These processes have been implemented in plants at full scale with treatment capacities that are comparable with the capacities required for the treatment of the AMD on the Witwatersrand. It would be too simplistic to rule out all other technologies only on the grounds that there are no installations of comparable size, since some of the technologies may be applied successfully after further development.

In the evaluation of the technologies, it needs to be taken into account that the AMD problem on the Witwatersrand is currently the biggest AMD problem in the world. Nowhere have plants been constructed to meet the level of demand that is required on the Witwatersrand and South Africa is thus embarking on untested territory. It is therefore sensible also to evaluate technologies that have not been tested to the scale required. It will therefore be advisable to test the alternative technologies that show potential at demonstration scale to assess all risks.

A reduction in the production of residue products, relative to the conventional RO process, is anticipated for the following processes:

- Fe-CN process;
- Alternative RO (MiWaTek);
- Biosure;
- Paques; and
- Electrocoagulation.

A reduction in the production of residue products would reduce some of the problems associated with the disposal of the residue products, which would have a major impact on the economics of the operation, especially if the indefinite horizon of the problem is taken into account.

It would thus make sense to be able to analyse these processes in detail, by constructing pilot plants with the capacity to treat between 5 and 10 Mℓ/d in order to research and demonstrate the suitability of the various processes.

The Fe-CN process appears to have great potential; however, there are still significant issues that need to be cleared and proven. Due to the perceived advantages, it is mandatory that this process be investigated in detail to either prove it is safe, or to motivate its rejection.

The Biosure process has already been studied by the Water Research Commission in association with ERWAT. Clarity needs to be obtained regarding the licensing of the process and the ownership of the intellectual property.

The ownership of the Paques biological process is clear and it would only be necessary to negotiate the rights to construct such a plant. The owners of the intellectual property would inevitably have to be involved. The approach to the recommended research should ensure that South Africans are trained and educated in the process.

The capacity of the biological processes (Biosure and Paques) to treat the volume of AMD is restricted by the available organic material. The total volume of sludge produced by the wastewater treatment works in the south of Johannesburg and on the East Rand is inadequate to adequately treat all the AMD. Additional sources of organic material would have to be researched and sourced.

The owners of the intellectual property of the alternative RO keep it very confidential and it is difficult to obtain adequate information to fully evaluate the process. The advantages of the process appear to be very attractive, thus warranting further research.

AMD water is rising in the basins and urgent action is required. There is simply no time left for experimentation in searching for the optimal solutions for implementation in the near future. If any proven technologies are used, the solution that is implemented might later be shown to have contained some element of 'non-optimal' expenditure, since it is expected that some of the innovative technologies that must still be proven will have significantly lower OPEX than the Reference Project.

Taking into consideration all the information presented in this section, the only solution that can be implemented with a reasonable degree of risk is the HDS process followed by conventional RO. This process train should be analysed in detail, as it is able to address all associated risks and costs can be assigned to the elimination of the risks. This will then be the base case against which all other processes would be compared and measured. However, since this base case produces large volumes of HDS, which is expensive to dispose of, it may later be shown that it is not the best long-term solution if some of the other technologies prove themselves. Note that options to beneficiate the sludge streams and the brine are being researched and could in future reduce the liability associated with the waste disposal for the conventional multistage RO process.

It is important to note that the concentration of uranium in the AMD exceeds the SANS-241 (2011) limit by several factors, even at the 50th percentile. Special treatment processes will be required to reduce this to the SANS-241 requirements. Refer to DWA AMD FS 2013,

Study Report No. 5.4: “**Treatment Technology Options**” for background on the Ion Exchange process which is capable of removing the uranium in AMD. It is suggested that allowance be made for Ion Exchange to be included before the HDS plant in the Reference Project.

3 REFERENCE TECHNOLOGY RESIDUE CHARACTERISTIC

3.1 High Density Sludge (HDS) Process for Neutralisation

3.1.1 Estimated Quality and Quantities of Residue Products

The residue product produced by the HDS process is sludge, as described in this section.

The estimated quality and quantity of sludge from the proposed HDS process for initial feed water qualities at the 95th percentile are summarised below in **Table 3.1**. The following are noted:

- A dewatering facility will reduce the waste stream significantly if the required capacity for storage is not available for the sludge waste stream.
- Given the feed water quality in the Eastern Basin, the limestone pre-neutralisation component may not be required and the HDS lime dosing process may be sufficient. If the sulphate concentrations are low and Gypsum precipitation is not required then the reaction retention time can be reduced to 30 minutes. This would result in reduced capital and operating costs, as limestone storage and dosing equipment would not be required; fewer chemical reactors would be required; and chemical and sludge handling costs would be significantly reduced.
- It is recommended that a laboratory-scale test be performed in order to more accurately determine the removal efficiency of uranium by precipitation.
- A Cost-Benefit Analysis (CBA) would also be required to determine what is to be gained if uranium can be recovered in commercial usable quantities.

Table 3.1: Estimated sludge quantities and composition for feed water qualities at the 95th percentile

Precipitate (dry basis)	Units	Sludge composition from the Limestone Pre-neutralisation and HDS process for feed water quality at the 95 th percentile		
		Western Basin (95 th)	Central Basin (95 th)	Eastern Basin (95 th)
Fe(OH) ₃	%	29.9%	10.0%	37.3%
Fe(OH) ₂	%	1.3%	0.4%	24.9%
Al(OH) ₃	%	2.7%	28.4%	1.9%
Mn(OH) ₂	%	2.4%	3.9%	1.6%
CaF ₂	%	0.0%	0.0%	0.0%
Ca ₃ (PO ₄) ₂	%	0.0%	0.0%	0.0%
Mg(OH) ₂	%	0.0%	0.0%	0.0%
CaCO ₃	%	20.3%	11.8%	34.3%

Precipitate (dry basis)	Units	Sludge composition from the Limestone Pre-neutralisation and HDS process for feed water quality at the 95 th percentile		
		Western Basin (95 th)	Central Basin (95 th)	Eastern Basin (95 th)
CaSO ₄	%	43.5%	45.4%	0.0%
Uranium precipitate	% as U kg/d	0.0027% 4.05	0.0313% 29.67	0.0715% 33.6
Total sludge (dry)	t/d	140.3	94.8	47.0
Total (if filter cake @ 65% solids)	t/d	215.9	145.8	72.3
Total (if filter cake @ 65% solids)	m ³ /d	134.9	91.1	45.2
Total (if sludge @ 10% solids)	t/d	1 403.3	947.9	469.7
Total (if sludge @ 10% solids)	m ³ /d	1 275.7	861.7	427.0

Note: The quality of lime is unknown and therefore not included in the calculation.

In cases where the sludge composition does not add up to 100%, this is because of the rounding of percentages for individual precipitates.

The estimated quality and quantity of sludge for feed water qualities at the 50th and 75th percentiles are shown in **Table 3.2** below.

Table 3.2: Estimated sludge quantities and composition for feed water qualities at the 50th and 75th percentile

Precipitate (dry basis)	Units	Sludge composition from HDS process for feed water quality at the 50 th percentile			Sludge composition from HDS process for feed water quality at the 75 th percentile		
		Western Basin (50 th)	Central Basin (50 th)	Eastern Basin (50 th)	Western Basin (75 th)	Central Basin (75 th)	Eastern Basin (75 th)
Fe(OH) ₃	%	37.5%	8.1%	11%	32.5%	7.2%	21.9%
Fe(OH) ₂	%	1.6%	0.3%	8%	1.4%	0.3%	14.6%
Al(OH) ₃	%	2.5%	39.1%	0%	2.8%	31.5%	0.0%
Mn(OH) ₂	%	2.7%	8.0%	1%	2.5%	6.2%	1.1%
CaF ₂	%	0.0%	0.0%	0%	0.0%	0.0%	0.0%
Ca ₃ (PO ₄) ₂	%	0.0%	0.0%	0%	0.0%	0.0%	0.0%
Mg(OH) ₂	%	0.0%	0.0%	0%	0.0%	0.0%	0.0%
CaCO ₃	%	7.2%	25.7%	80%	13.6%	19.0%	62.3%
CaSO ₄	%	48.5%	18.8%	0%	47.2%	35.9%	0.0%
Total sludge (dry)	t/d	77.6	43.5	50.2	104.4	58.9	44.4
Total (if filter cake @ 65% solids)	t/d	119.3	67.0	77.2	160.6	90.6	68.2
Total (if filter cake @ 65% solids)	m ³ /d	74.6	41.8	48.2	100.3	56.6	42.6

Precipitate (dry basis)	Units	Sludge composition from HDS process for feed water quality at the 50 th percentile			Sludge composition from HDS process for feed water quality at the 75 th percentile		
		Western Basin (50 th)	Central Basin (50 th)	Eastern Basin (50 th)	Western Basin (75 th)	Central Basin (75 th)	Eastern Basin (75 th)
Total (if sludge @ 10% solids)	t/d	775.7	435.2	501.6	1 043.6	589.0	443.6
Total (if sludge @ 10% solids)	m ³ /d	705.2	395.6	456.0	948.7	535.5	403.2

Given that the manganese concentrations in the Central and Eastern Basins are relatively low, this two-stage precipitation process might be an alternative worth considering for these two basins.

The second clarifier after the gypsum crystallisation reactor will produce sludge consisting mainly of gypsum and manganese hydroxide. Depending on the manganese hydroxide content, this sludge could have some re-use value in the form of crude building materials.

3.2 Desalination by Conventional Reverse Osmosis

3.2.1 Estimated Quality and Quantities of the Residue Products Produced by the RO Process Step only

The desalination of the neutralised AMD will produce the following residue products:

- Sludge, in the form of dewatered gypsum; and
- Brine, in cases where the treated water specifications cannot be met as a result of the concentrations of the monovalent ions (sodium and chloride) exceeding the required standards.

The quantities of waste to be produced are calculated in the sections below. It should be taken into account that the RO process requires mandatory pre-treatment of the AMD. For the purposes of this report it was assumed that a limestone pre-neutralised and a HDS process were used for pre-treatment. Estimations of the quantity of final waste products produced by the RO process must also include the volumes of waste products produced by the pre-treatment process (HDS).

Two types of sludge are produced in a reverse osmosis AMD treatment plant. The first is HDS sludge, as discussed in section 3.1 above. The second is gypsum sludge, which is produced in each of the gypsum precipitation steps. A portion of the gypsum could possibly be offset into the market at no cost to the client. This sludge is not hazardous and could possibly also be discharged on to nearby tailings dams. Alternatively, sludge storage facilities would have to be constructed in order to manage the sludge produced.

The estimated sludge production volumes and composition for feed water quality at the 95th percentile, produced by the RO process step only, are shown for each basin in **Table 3.3** below.

Table 3.3: Estimated sludge production and composition for feed water quality at the 95th percentile produced by the RO process step only

Precipitate (dry basis)	Units	Sludge composition for feed water quality at the 95 th percentile		
		Western Basin	Central Basin	Eastern Basin
Fe(OH) ₂	%	0%	0%	0%
Al(OH) ₃	%	0%	0%	0%
Mn(OH) ₂	%	0%	0%	0%
CaF ₂	%	0%	0%	0%
Ca ₃ (PO ₄) ₂	%	0%	0%	0%
Mg(OH) ₂	%	2%	17%	13%
CaCO ₃	%	1%	0%	0%
CaSO ₄	%	97%	83%	87%
Total sludge (dry)	t/d	40.8	163.7	242.7
Total sludge (filter cake) 65% solids	t/d	62.8	251.9	373.3
	m ³ /d	39.2	157.4	233.3
Total sludge (slurry) 10% solids	t/d	408.1	1 637.2	2 426.5
	m ³ /d	371.0	1 488.4	2 205.9

The estimated sludge production volumes and composition for feed water quality at the 50th and 75th percentiles, produced by the RO process step only, are shown for each basin in **Table 3.4** below.

Table 3.4: Estimated sludge production and composition for feed water quality at the 50th and 75th percentiles produced by the RO process step only

Precipitate (dry basis)	Units	Sludge composition for feed water quality at the 50 th percentile			Sludge composition for feed water quality at the 75 th percentile		
		Western Basin	Central Basin	Eastern Basin	Western Basin	Central Basin	Eastern Basin
Fe(OH) ₂	%	0%	0%	0%	0%	0%	0%
Al(OH) ₃	%	0%	0%	0%	0%	0%	0%
Mn(OH) ₂	%	0%	0%	0%	0%	0%	0%
CaF ₂	%	0%	0%	0%	0%	0%	0%
Ca ₃ (PO ₄) ₂	%	0%	0%	0%	0%	0%	0%
Mg(OH) ₂	%	7%	11%	10%	2%	13%	14%
CaCO ₃	%	0%	0%	2%	0%	0%	0%
CaSO ₄	%	92%	89%	88%	98%	87%	86%

Precipitate (dry basis)	Units	Sludge composition for feed water quality at the 50 th percentile			Sludge composition for feed water quality at the 75 th percentile		
		Western Basin	Central Basin	Eastern Basin	Western Basin	Central Basin	Eastern Basin
Total sludge (dry)	t/d	55.0	173.9	102.2	44.7	170.0	164.1
Total sludge (filter cake) 65% solids	t/d	84.6	267.5	157.2	68.8	261.6	252.5
	m ³ /d	52.9	167.2	98.3	43.0	163.5	157.8
Total sludge (slurry) 10% solids	t/d	550.2	1 739.0	1022.0	446.9	1 700.4	1 641.0
	m ³ /d	500.2	1 580.9	929.1	406.3	1 545.8	1 491.8

Note: In cases where the sludge composition does not add up to 100%, this is because of the rounding of percentages for individual precipitates.

The final handling and disposal of sludge is a high risk to the project and should be further investigated in the Feasibility phase. The following are some examples of disposal options that should be considered:

- Disposal of sludge to existing tailings facilities;
- Underground disposal of the sludges;
- Construction of a lined waste disposal facility to discharge and store sludge; or
- Placement of gypsum sludge into the market as a by-product.

3.3 Conclusions on Residue Characteristics

The sludge produced from the HDS process is non-hazardous; however, the disposal of this residual can potentially increase the risk and costs associated with the process. The sludge produced from the HDS process is a mixture of many different compounds including gypsum, iron hydroxide and manganese hydroxide. Due to the lack of purity of the substance the likelihood of selling this residual as a by-product is small and the waste will have to be disposed of in a safe and sustainable manner.

The sludge can potentially be disposed of on existing tailings dams. However; it is not known what the remaining life of such tailings facilities is and who will accept the responsibility (*i.e.* mining companies, DWA or implementing agent of the LTS) in the future. Therefore it is likely that lined disposal facilities will have to be built which increase the footprint, the capital expenditure and operating costs of the infrastructure. Due to the nature and consistency of the HDS sludge, dewatering of the sludge will prove very difficult and consideration will have to be made in the design to reduce blockages of structures and piping.

Residuals from the RO treatment process include gypsum sludge and potentially a brine solution if monovalent concentrations of the process water do not meet required limits. The gypsum produced is a highly pure form of gypsum, therefore resale of this by-product is

possible. As with the HDS sludge, if resale is not possible, disposal on existing tailing dams or to new disposal facilities is required. If brine cannot be reintroduced to the treated water, lined evaporation ponds will also be required to dispose of the brine.

The AMD from all three basins contains uranium. If uranium removal such as Ion Exchange is not included upstream of the HDS and RO treatment processes, it is likely that the uranium will concentrate within the residual streams from the HDS and RO treatment processes. The levels of uranium in the residual streams may impact of the resale or disposal options. Careful consideration and assessment are required in order to assess how the uranium content will influence the disposal of the residuals and if uranium removal upstream of the treatment processes is required to reduce disposal risks in the downstream processes.

4 SHORT-TERM RESIDUE DISPOSAL

4.1 Summary of the disposal options proposed/used in the short-term intervention

The Short-Term Intervention (STI) will neutralise the AMD, but will generate substantial quantities of voluminous iron-rich and potentially radionuclide-impacted sludge to be disposed of. Historically, HDS plants of mines discharged the resultant sludge along with their tailings to tailings dams, as a co-disposal approach. The STI proposes to continue with the disposal of residue sludge to tailings dams, or open pits, or possibly as back-fill into abandoned mine-workings. This approach could create a number of potential problems if these solutions were adopted in the long-term.

4.2 Comment on the short-term disposal options

The following comments can be made on the short-term disposal options:

- i) The tailings dams, open pits and mine workings are owned by various mine groups. For the STI, agreements have been put in place for the management of waste sludge, but for the LTS there is no agreement that the tailings dams, open pits or abandoned mine workings can be used to receive the sludge, either by the facility owners or the authorities;
- ii) The liability for the future closure and rehabilitation of the tailings dams, open pits and abandoned mine-workings that receive sludge has apparently not been determined;
- iii) A cursory review of the legislation suggests relaxation of the legislation may be required to facilitate timeous authorisation for such waste disposal practices, which does not appear to have been accounted for in the Short-Term studies;
- iv) The Short-Term studies do not appear to have determined the capacity of the available tailings dams, open pits or abandoned mine workings in the Central and Eastern basins to receive the projected sludge volumes and characteristics - The extent of the waste produced that is destined for disposal must be minimised as to not replace the current slimes dams with even larger brine and sludge deposits. However, in the Western Basin waste is already being co-disposed and heads of agreement have been reached with ERGO in the Central and Eastern Basins. The disposal is within the existing authorisation.
- v) The Short-Term studies do not appear to have confirmed the engineering requirements to allow the tailings dams, open pits or abandoned mine workings to receive the projected sludge volumes and characteristics;
- vi) The Short-Term studies do not appear to have demonstrated that the sludge can be stabilised/managed to allow future disposal to tailings dams, open pits or abandoned mine workings, without undue environmental impact;

- vii) The long-term environmental liability for such sludge disposal to existing tailings dams, open pits or abandoned mine workings has not been determined in the Short-Term project;
- viii) The need for, the location of, and design basis for dedicated hazardous waste storage/disposal facilities to receive the sludge will have to be considered in the LTS;
- ix) Heads of agreement have been reached to dispose waste sludge to existing landfills or other waste disposal facilities, has not been determined in the Short-Term project;
- x) The opportunity to beneficiate the waste sludge has not been determined in the STI.
- xi) Commercial arrangements for blending, conveying and storage of the wastes has not been addressed in the STI;
- xii) The return water from the TSFs after the tailings deposition has ceased has not been addressed in the STI;
- xiii) Where the management of sludge will have an impact on water resources, a water use license will be required and will have to be addressed.
- xiv) Permitting and licensing of the TSFs, including monitoring and operation towards closure, has not been addressed in the STI; and
- xv) Delayed issuance of a closure permit to the TSF owner – this can be costly in the long run and can incur substantial costs.

All of the above potential problems, including others such as socio-economic and environmental challenges, should be addressed in the EIA which will cover both the STI and the LTS.

TCTA has confirmed that sludge dewatering, either mechanically or physically, will not be required in the STI;

Risks associated with the waste sludge management and disposal infrastructure that appear to have been addressed in the STI, include:

- Eventual classification of the waste sludge – hazardous or general;
- Environmental and licensing constraints and delays – pipelines and disposal areas;
- Liner requirements;
- Blockage and reserve capacity;
- Duty and standby pumps;
- Capacity of the receiving facility (pit, shaft, TSF); and
- Return water system security and operation, and electrical supply to these, after the TSF owners no longer use these facilities,

HDS has internationally been placed in abandoned deep mines or in pits dug on surface mines, to take advantage of its excess alkalinity (due to unconsumed hydrated lime), but this is only appropriate if the environment, that the sludge is being placed into, is not acidic. If the

sludge is exposed to sufficiently acidic water, the sludge can re-dissolve, neutralising the pH somewhat, but increasing the dissolved metal content.

4.3 Potential to use STI options for medium- and long-term sludge management

The contracts and working agreements with the mining groups that have been obtained with respect to sludge disposal underground, in-pits or in abandoned mine-workings may not be a long-term solution, as the mines will not continue operating indefinitely and the use of their facilities for HDS disposal may delay closure of these facilities. Additionally, the tailings, in-pits or abandoned workings disposal options all have limited capacities and thus alternative disposal options will need to be investigated for the LTS.

The tailings, in-pit or abandoned workings disposal options are cost effective and will be considered during procurement of the LTS if any proposals on such options are received. These options may also be economical in the medium term while other disposal methods are licensed, financed and constructed. The long-term objective of obtaining mine closure for all mines that have permanently ceased operations should not be compromised when considering such disposal agreements. These facilities may have to be purchased by the plant operator for the LTS to ensure longer-term disposal to these facilities can occur. In doing so, it should be carefully considered who assumes the financial and closure costs for the tailings storage facility (TSF) once the mine(s) have ceased operations.

In the identification of waste disposal sites, consideration must be given to the long-term objectives for land use and development of various stakeholders, such as Ekurhuleni Metropolitan Municipality, the Gauteng Department of Agriculture and Rural Development (GDARD), etc. The GDARD embarked on an initiative to enable the reclamation of mine residue areas for beneficial use. Waste disposal from AMD treatment should not jeopardise the objectives of these initiatives.

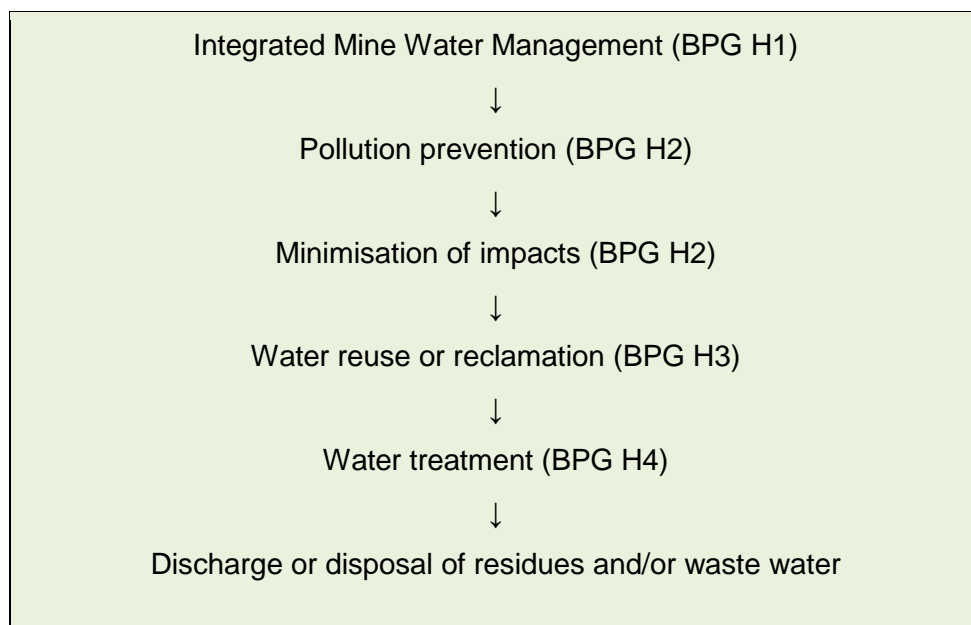
5 MANAGEMENT OF LONG-TERM TREATMENT RESIDUES

5.1 Best practice guidelines

DWA has released a number of guidelines that document best practice for water and waste management. These are used as guidelines as to what DWA considers to be best practice with respect to resource protection and residue management:

- BPG H1: Integrated Mine Water Management (2008)
- BPG H2: Pollution Prevention and Minimisation of Impacts
- BPG H3: Water Reuse and Reclamation
- BPG H4: Water Treatment

These documents form a hierarchy as follows:



In considering the residue management options for the Reference Project, the hierarchy noted above was used to reduce the impacts of any waste facilities on storm water minimise impacts on groundwater and surface water bodies and protect slopes from erosion.

5.2 Potential to recover useful products

A paradigm shift has taken place in the handling and management of treatment residues such as sludge and brines. The recovery residue products with commercial value are presently being researched and actively pursued in the market. The Global Acid Rock Drainage (GARD) Guide, sponsored by the International Network for Acid Prevention (INAP) with the support of the Global Alliance, identifies a number of potential options for the beneficiation of AMD residues.

The recovery of useful products from the treatment process residue streams may include:

- Metals recovery;
- Supplements for mine land rehabilitation and re-vegetation, such as $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$;
- Alkali recovery, such as CaCO_3 ;
- Building- and construction-related materials, as used in gypsum boards;
- Beneficial use of brine in the cultivation of halophilic organisms, such as algae containing high β -carotenes and other nutritional supplements;
- Recovery of saleable products such as sulphur and magnesium salts;
- Agricultural use (e.g. fertiliser);
- Supplements in cement manufacturing;
- Gravel from sludge;
- Metal adsorbents used in industrial wastewater treatment;
- Pigment (ferrihydrite) for paints; and
- Uranium recovery.

Research and development work is on-going, but no full-scale beneficiation of AMD residue residues has been demonstrated other than the recovery of clean gypsum at the eMalahleni Water Reclamation Plant. The incentives driving the recovery of by-products include the following:

- Reduction of sludge and brine products, which require handling and perpetual disposal, with associated long-term environmental liabilities;
- Generation of a revenue stream to partly or fully offset the on-going treatment cost; and
- Contribution to the long-term sustainability of mine water treatment projects.

The key aspects of successful recovery of by-products in the treatment of AMD are as follows:

- The target by-products must be selectively removed by minimising the co-precipitation of compounds that would degrade the quality of the by-products.
- By-product recovery, as a project objective, will have an impact on the mainstream treatment process in terms of unit treatment, process selection and sequence of treatment processes.
- It is necessary to take into account the impact of by-product recovery, as a project objective, on the mainstream treatment process in terms of unit treatment process selection and sequence of treatment processes.
- Chemical (reagent) dosing in the mainstream treatment process must take into account the impact on the potential for and composition of by-products.
- To what extent the revenue generated from the sale of by-products can cover the cost of treatment (i.e. affordability).

The initiatives of Anglo Coal, BHP Billiton and the Council for Scientific and Industrial Research (CSIR) in Witbank (eMalahleni) demonstrate that the recovery of products from waste gypsum is potentially viable. The CSIR has patented the GypSLiM process, which is capable of producing sulphur, limestone and magnesite from the waste gypsum produced during the neutralisation of acid mine water, provided that the neutralisation approach is compatible with GypSLiM. For the eMalahleni plant, an industrial waste recycling company (Sulphide Tech) has been established to assist with by-product recovery from the AMD treatment plant.

The GypSLiM process converts waste to useful products; it provides the means for AMD treatment through the recycling of calcium carbonate produced in the process; and it neutralises acid. In the GypSLiM process, the gypsum is converted to produce limestone and sulphur and if any magnesium pollutants are present in the sludge, magnesite is produced. The resultant limestone can be recycled to the point where acid is neutralised, or it can be sold as a purified product, along with the sulphur and magnesite that are also produced. A secondary step to produce cement and lime can be added to the process, or the limestone can be sold to cement manufacturers for that purpose.

Two types of sludge will be produced in the treatment plant of the Reference Project. The first is HDS consisting mainly of precipitated iron and manganese. Secondly, gypsum sludge will be produced from each of the gypsum precipitation steps.

As discussed earlier, a portion of the gypsum could possibly be offset into the market at no cost to the client. This gypsum portion would not be hazardous.

Because the market for the gypsum is not known and the Reference Project will not produce separated materials, sludge storage will be required for storage of the HDS sludge

Consideration must also be given to the management of uranium. If an Ion Exchange step is included before the HDS plant, the uranium in the AMD can be reduced to acceptable limits and the sludge generated by the HDS plant will not be hazardous. However, if the Ion Exchange is not included, then the HDS sludge will contain a large portion of the uranium that is in the raw AMD and the sludge is likely to be classified as hazardous.

It is suggested that allowance be made for Ion Exchange to be included before the HDS plant in the Reference Project. The resin that is used in the Ion Exchange process has to be regenerated at intervals, of which the frequency is dependent on the uranium concentration. A residual containing uranium is produced during the regeneration process and must be disposed of in a safe and sustainable manner. It is recommended that a waste management contractor be procured to collect the residual after each regeneration. The contractor can extract and sell uranium from the residual. More information on Ion Exchange is included as Appendix A of DWA AMD FS 2013, Study Report No. 5.4: **“Treatment Technology Options”**.

The long-term study takes into consideration and assesses alternatives, including the waste streams that may be generated by the reference HDS plant and any subsequent desalination technology applied after the HDS pre-treatment. The following considerations are pertinent:

- The short-term HDS neutralisation technology produces a waste sludge stream of mixed iron oxides and gypsum for disposal to pit-infilling and co-disposal to tailings dams as the only proposed viable options.
- Modifications to the HDS neutralisation technology could be implemented to provide for the recovery of iron-rich sludge (still dominated by gypsum) and a cleaner gypsum waste stream.
- There is potential for recovering metals from AMD sludge, but this has not yet been demonstrated at a commercial scale. Similarly, although the eMalahleni AMD treatment plant produces gypsum, which is being used in construction activities, the wider commercial recovery of gypsum has not been demonstrated to be sustainable.
- Vendors offering to recover metals and gypsum from AMD sludge would also need to be provided with appropriate sludge disposal facilities in the event that recovery becomes non-commercial.
- Earth Metallurgical Solutions (a company which provides sustainable environmental solutions to a range of industries, with a focus on production of clean water and of extraction of value from effluent streams) have completed trials demonstrating that AMD and AMD brines can be converted to potable water and saleable by-products, including fertiliser, explosives and thermal salts for concentrated solar power plants. Other vendors make similar claims that AMD can be treated without extensive HDS treatment and multi-phase reverse osmosis, but these processes have not been demonstrated at full scale.
- Eutectic freeze desalination is being developed at the University of Cape Town. This technology has potential to selectively recover pure salts from brine streams. The bulk of the brine salts could then be sold to chemicals markets instead of being landfilled. Water is recovered and re-treated in RO.
- Waste beneficiation options for the waste streams that may be generated by the HDS plants and by any subsequent desalination technology will be considered during implementation if any such proposals are received from service providers.

The Water Research Commission (WRC) made a submission in respect of the beneficiation of AMD in terms of:

- Processing of sludge derived during AMD neutralisation; and
- Uses of sludge derived during total removal of salts from AMD, including:
 - Cover for tailings;
 - Building materials;
 - Agricultural land applications;
 - Metal adsorbent in industrial wastewater treatment;

- Carbon dioxide sequestration; and
- Other uses, including utilisation as a rock dust substitute for explosion control and sludge ‘gravel’.

The WRC submission concluded, however, that “the cost of sludge manipulation and limitations around use of the end product essentially dictate that AMD-derived sludge are dumped appropriately” and that “decision-makers need to be clear that any venture to treat AMD to potable standards with the concomitant aim of selling the by-products is not going to generate substantial profit, if any”.

Previous research supported by the WRC demonstrated that “co-disposal of HDS-sludge and coal discard offers an effective alternative to disposal of HDS-sludge in lined landfills”.

The following conclusions have been reached regarding the long-term waste disposal strategy:

- According to the recommendation of the WRC, “co-disposal of HDS-sludge with other metal leachable residues, including pyritic mine tailings, could also offer an alternative to disposal of HDS-sludge to lined landfills”.
- However, given the short-term life of disposal to the West Wits Pit and identified tailings dams, the disposal of HDS sludge as a general waste in lined dams is used for the Reference Project.
- Similarly, as also demonstrated at eMalahleni, the disposal of the brine salt stream from the reverse osmosis desalination, in the absence of proven technologies to recover or beneficiate the brine stream, requires disposal in lined dams for the Reference Project.
- Some of the alternative innovative technologies discussed in section 2 display huge potential, not just with regards to its treatment capabilities, but also a reduction in the residue streams produced and its ability to recover products that might be sold to offset the cost of treatment. The opportunity should be given to such technologies to prove themselves through pilot plants as is recommended in DWA AMD FS 2013, Study Report No. 5.4: “**Treatment Technology Options**”. If such technologies can be proven, it may be considered for implementation in the long-term on a larger scale.

5.3 Disposal options

All long-term AMD treatment technologies produce residues (e.g. sludge, brines and spent media) or emissions (e.g. gases). These residues and emissions contain the elements and compounds removed from the AMD and the additives and supplements dosed in the treatment process.

No consideration of the long-term AMD treatment technologies would be complete without an understanding of these residues and emissions as they relate to the following:

- Relative production in terms of volumes and masses;

- Typical characteristics in terms of chemical composition (e.g. hydroxide, sulphide and nitrogen and phosphorous (NP)) and physical properties (i.e. consistency, volatility and ability to dewater);
- Long-term stability and potential to leach or release hazardous or saline components.
- Hazardous classification and rating; and
- Potential environmental impacts.

The residues from the present treatment options being considered can broadly be classified into the following two categories:

Sludge: a slurry or dewatered cake containing precipitates of diverse composition;

Brines: a solution of salts in high concentrations.

The handling and disposal of sludge must take the following into account:

- Dewatering and compaction ability;
- Slurry density and moisture content;
- Volume and rate of production;
- Metal stability and available alkalinity;
- Radio-nucleotide presence and stability;
- Sludge composition; and
- Economics.

The sludge disposal options include the following:

- Engineered sludge ponds – **Recommended for further investigation;**
- Underground mine-workings, especially as a backfill material – Further investigation is required. It may be viable if the mine void into which it is disposed of is isolated sufficiently from the main void;
- Open pit mine-workings – Associated risks too high;
- Co-disposal with mine tailings and waste – The question remains what happens when mine ceases operations and who retains the long-term risk of the facility;
- Incorporation into rehabilitation covers of mine tailings and waste – The question remains what happens when mine ceases operations and who retains the long-term risk of the facility; and
- Landfilling after amendment with a stabilising material – HDS sludge is very gelatinous, will require substantial amount of stabilising material and will then not be cost effective.

Due to third party concern regarding leaching of metals and other contaminants from the waste back into the groundwater, underground disposal was not considered for further investigation. Underground disposal may in fact be a viable disposal option, and this is primarily dependent on the upstream processes relating to removal of contaminants and

providing a waste product without metals, or the identification of possible sites where the leaching of metals may not be an issue. During procurement of the LTS, proposals including the option of underground disposal of waste will be compared against the Reference Project and if it provides acceptable risks at a lower cost than the Reference Project it might be considered for implementation.

Brine disposal is much more challenging and the disposal options include the following:

- Incorporation into a mine waste or tailings stream. The salt water will be transported with the slurry, with the salts remaining after evaporation, then being incorporated into the matrix of the final deposited tailings – Question remains what happens when mine ceases operations. Who retains the long-term risk of the facility?;
- Irrigation and potential cultivation of salt-resistant plants – Associated risks too high (salts might leach to groundwater and eventually end up in surface water resources;
- Solar evaporation ponds, possibly with some wind-assisted enhanced evaporation features – **Recommended for further investigation**;
- Discharge and dilution in a sanitary sewer – Waste water treatment works might not have the capacity to accept a higher salt load;
- Mechanical or thermal evaporation and crystallisation – Energy input required for this option too high, will not be cost effective;
- Beneficial use in the cultivation of halophilic algal species of commercial value – Can be viable, but risk of salts contaminating ground-or-surface water resources are too great;
- Pipeline, road or rail transport to sea – Associated CAPEX & OPEX too high; and
- Deep well injection – Associated risks too high (the salts might just be circulated).

The final handling and disposal of sludge are high risks to the project and should be investigated in detail during implementation.. The following options could be considered if proposals on such options are received during implementation:

- Disposal of HDS and brine to existing tailings facilities;
- Construction of a lined waste-disposal facility to discharge and store HDS and brine; and
- Offset of gypsum sludge into the market as a by-product.

5.4 Sludge storage facilities

Without detailed knowledge of the quantities of residues to be generated and the characteristics of this material as deposited slurry, the identification of potential class GLB⁺ sites for the disposal of the waste was based on certain assumptions with respect to waste production rates and plant size. These disposal assumptions are based on the premise that the wastes are not considered as part of mine wastes, but as industrial waste products. The waste disposal aspects are therefore considered in terms of NEMA (107:1998) and NEMWA (59:2008) and not MPRDA (28:2002).

Waste production rates were assessed at the 75th percentile for water treatment plants in each of the three basins. For the HDS and RO plants, the areas and heights of the waste sites required for 50 years' production are estimated in **Table 5.1**. The brine solution could be disposed of within these areas, with the water being evaporated by sun and wind. Brine will be disposed of in a lined facility due to its mobility. If co-disposed with sludge the sludge will be disposed of in a facility designed for brine which is usually a much more expensive liner system than for dewatered sludge. If the brine is disposed of with a liquid sludge then the decant water will be contaminated by brine and separate decant water treatment will again be required. Potential waste sites were identified using satellite imagery and the possible sites are shown in **Figure 5.1**.

Table 5.1: Conceptual sizing of waste sludge management sites

Characteristic	Units	Basin		
		Western	Central	Eastern
Solids volume	t/d	135.5	208.1	189.5
In-situ sludge volume (50 years)	m ³ x 10 ⁶	2.56	3.8	3.3
Length on ground	m	700	990	838
Width on ground	m	560	565	513
Area on ground	m ²	392 000	559 350	429 894
Max height of sludge dam at end of life	m	10	10	14

It is noted that land would have to be acquired for the sites and the necessary licensing would have to be in place. The anticipated SSFs are likely to be classified as dams with a safety risk, with the applicable provisions of the NWA (36:1998) applying. These requirements could only be addressed during or after the EIA for the water treatment sites and the pipeline routes.

5.4.1 Management of Sludge Disposal Facilities

Certain aspects of the management of the Reference Project disposal options need to be considered. On the basis that the sludges would be de-listed to general wastes, the Reference Project case is for a long-term class GLB⁺ waste disposal facility, properly lined. The following aspects would have to be taken into account in relation to the operation and management of a class GLB⁺ site:

- **Wall raising:** Due to the gelatinous nature of iron-rich gypsum sludges, the material is not suitable as a wall-building material and therefore a conventional tailings facility cannot be considered. To impound this material, an outer wall must be continuously constructed from an imported material such as waste rock. The facility will need to be lined, which will allow for the rock to be fairly permeable. The wall will need to be advanced at a sufficient rate so that adequate freeboard is maintained at all times. To maintain liner integrity, the walls will need to be raised over time away from the waste

body (called downstream construction). Due to this method, the volume of material to be used for each increment of wall raising will increase as the facility height increases. The upstream face of the wall will be 'padded' with a selected material, over which a geosynthetic clay liner (GCL) and a 1.5 mm HDPE liner will be placed. This conceptual analysis is based on a single cell facility. A phased facility can be considered to delay capital expenditure and to ensure a more manageable open liner area.

- Storm water on the waste and the rock walls will need to be contained, tested and treated if necessary before it can be released to the environment. To optimise the amount of storm water to be managed, it will be necessary to stage the development of the disposal sites and to isolate areas from rainwater when these are completely filled.
- Supernatant water in the facility from the HDS slurry disposal will need to be managed and returned to the plant for treatment but this will not be possible for brine co disposal scenarios.
- Delivery pipes will need to be monitored for leakage and wear and tear.
- Groundwater quality will need to be monitored.
- Any liner leak detection systems will need monitoring.
- Proper planning of the waste site closure construction work will be required. Due to the downstream construction, the outer wall slopes cannot be rehabilitated as the facility rises.
- Daily, weekly, monthly, quarterly and annual operational and dam safety inspections and surveys will be necessary.
- Post-closure monitoring will be necessary, which could continue for several decades after the last deposition.

5.5 Site selection and cost estimates for sludge storage facilities

The approach to costing the Reference Project included the following:

- **Desktop site selection:** This involved identifying potential sites for each basin in close proximity to the treatment works. These sites were evaluated according to the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998) and the most suitable sites (or the least undesirable as the case may be) were selected for the Prefeasibility level investigation. The sites were further investigated during the Feasibility phase which increased the level of confidence.
- **Area optimisation:** The extent of each waste disposal facility (on the respective site) was optimised to obtain the most cost-effective area-to-height relationship for the sludge disposal facility.
- **Preparation of a schedule of quantities and a cost estimate:** A cost estimate was carried out for each selected site. This included capital costs, operational costs over a

50-year lifespan of the facilities and closure costs. Schedules of quantities were compiled and the costs were determined to an accuracy of $\pm 40\%$.

The following are excluded from this section of the cost estimates, as these costs would be estimated as part of the civil, mechanical and electrical costs for the respective treatment plants which are covered in DWA AMD FS 2013, Study Report No. 6: **“Concept Design”**:

- Delivery pipes from the treatment plant to the fence boundary of the waste site;
- Return water pumps, pipes and pump station building; and
- Mechanical and electrical design.

5.5.1 Western Basin

- Western Basin: Sludge will be disposed of at a site within or close to the Western Basin treatment site.
- Western Basin Tunnel: Sludge will be disposed of at a site at the end or close to the end of the proposed tunnel running from the Western Basin (Western Basin Tunnel).

5.5.2 Central Basin

- Central Basin: Sludge will be disposed at a site within or close to the Central Basin treatment site.
- Central Basin Tunnel 1: Sludge will be disposed of at a site near the end of the potential tunnel from the Crown Mines Shaft in the Central Basin (Central Basin Tunnel: Option 1).
- Central Basin Tunnel 2: Sludge will be disposed of at a site near the end of the possible tunnel from the SWV shaft in the Central Basin (Central Basin Tunnel: Option 2).

5.5.3 Eastern Basin

- Sludge will be disposed of at a site within or close to the Eastern Basin treatment site.

5.6 Potential sludge disposal sites

The potential disposal sites identified for each of the options are indicated in **Figure 5.1**.

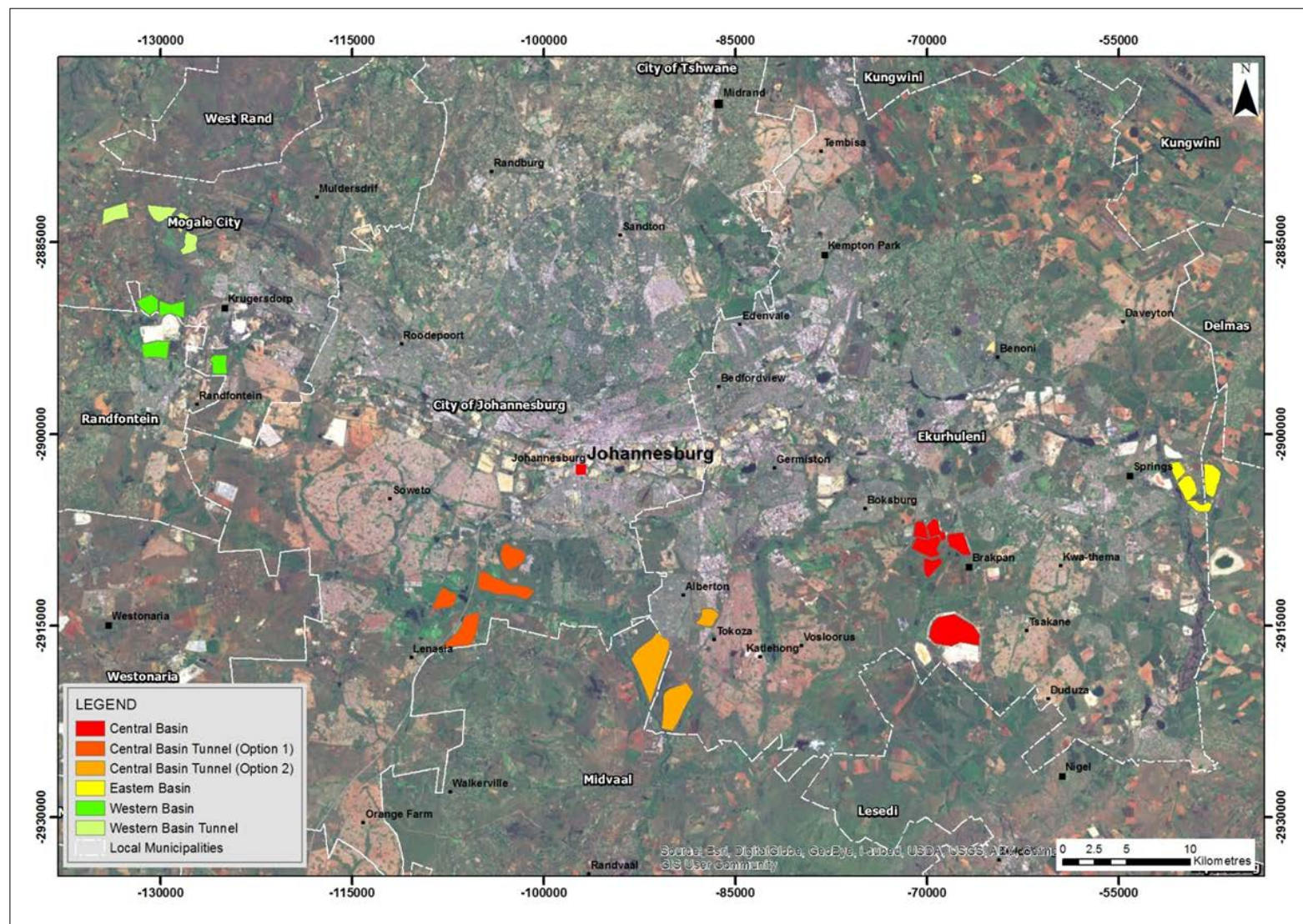


Figure 5.1: Proposed disposal sites

5.6.1 Western Basin disposal sites

The proposed disposal sites for the Western Basin are indicated in **Figure 5.2**.

The underlying geology of the sites is indicated in **Figure 5.3**. The following characteristics of the underlying geology were noted:

Site 1: Underlain by Malmani dolomites of the Malmani subgroup as well as rocks of the Black Reef Formation. The Black Reef formation consists mostly of Black Reef quartzite, but may also contain localised wads, carbonaceous shale and Basal conglomerates.

Site 2: Underlain by Malmani dolomites of the Malmani subgroup and as well as rocks of the Black Reef Formation and Government subgroup. The Black Reef formation consists mostly of Black Reef quartzite, but may contain localised wads and shale as well. The Government subgroup contains mostly quartzite, but also has beds of shale, siltstone and conglomerate.

Site 3: Underlain by a dolerite dyke and rocks of the Black Reef formation, with a portion of the proposed site being underlain by rocks from the Dwyka group. The Black Reef formation consists mostly of Black Reef quartzite, but may contain localised wads, carbonaceous shale and Basal conglomerates as well. The Dwyka group consists mostly of tillite.

Site 4: Same as Site 2.

The advantages and limitations of the proposed sites are listed in **Table 5.2**.

Table 5.2: Characteristics of proposed Western Basin sites

Site	Advantages	Limitations
1	<ul style="list-style-type: none"> Relatively flat or gently sloping terrain; Close to existing tailings dam, so site would not impose on prime development property; and Reduced visual impact, as tailings dam is already there. 	<ul style="list-style-type: none"> Negative visual impact, as it is close to a main road and nature reserve; and Power line will have to be relocated.
2	<ul style="list-style-type: none"> Relatively flat or gently sloping terrain; Close to existing tailings dam, so site would not impose on prime development property; and Reduced visual impact, as tailings dam is already there. 	<ul style="list-style-type: none"> Negative visual impact, as it is close to a main road and nature reserve; and Power line would have to be relocated and railway line runs through the site.
3	<ul style="list-style-type: none"> Relatively flat or gently sloping terrain; Close to existing tailings dam, so site would not impose on prime development property; Reduced visual impact, as tailings dam is already there; and Close to waste rock dump, which would reduce haulage costs. 	<ul style="list-style-type: none"> Upwind of residential area Close to cemetery (public might resist)
4	<ul style="list-style-type: none"> Relatively flat or gently sloping terrain; Close to existing tailings dam, so site would not impose on prime development property; and Close to waste rock dump, which would reduce haulage costs. 	<ul style="list-style-type: none"> Upwind of residential area; and Close to golf course and lake.

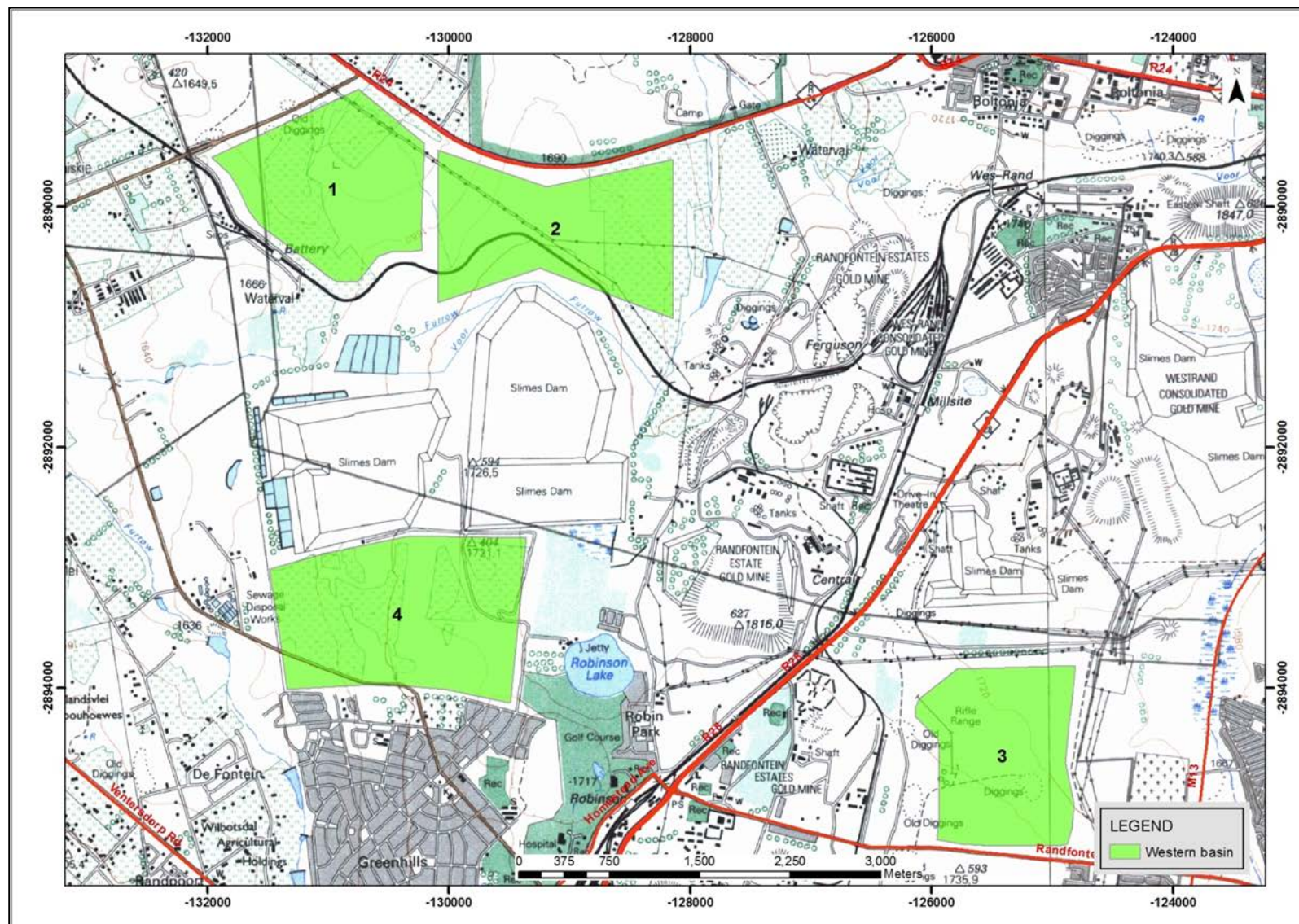


Figure 5.2: Proposed Western Basin sites (topographical map)

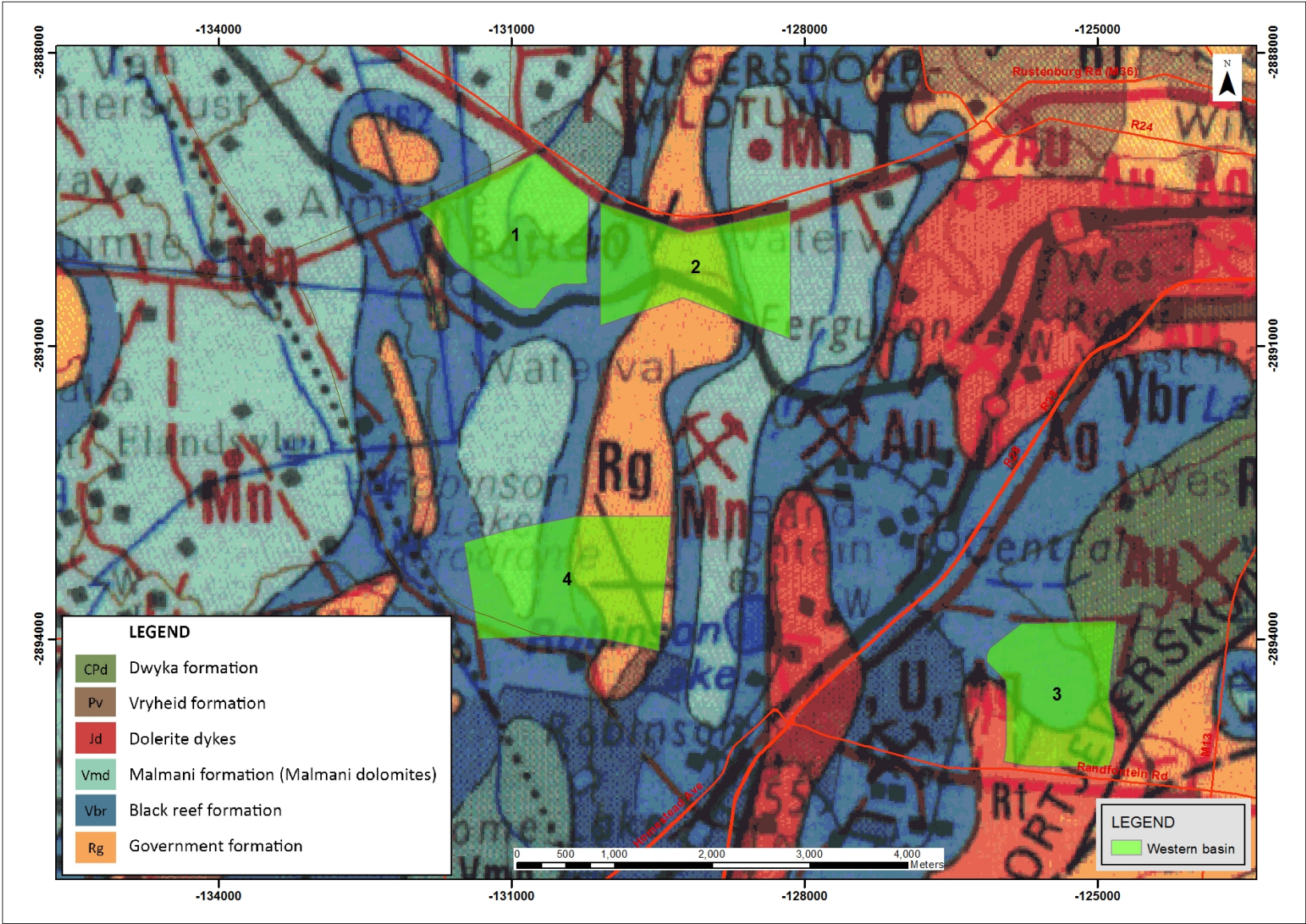


Figure 5.3: Proposed Western Basin sites (geological map)

5.6.2 Western Basin Tunnel disposal sites

The proposed sites for the Western Basin Tunnel are shown in **Figure 5.4**.

The underlying geology of the sites is shown in **Figure 5.5**. The following characteristics of the underlying geology were noted:

Site 1: Underlain by Malmani dolomites of the Malmani subgroup.

Site 2: Same as Site 1.

Site 3: Same as Site 1.

Site 4: Underlain by Malmani dolomites of the Malmani subgroup as well as rocks of the Black Reef formation. The Black Reef formation consists mostly of Black Reef quartzite, but may also contain localised wads, carbonaceous shale and Basal conglomerates.

The advantages and limitations of the proposed sites are listed in **Table 5.3**.

Table 5.3: Characteristics of proposed Western Basin Tunnel sites

Site	Advantages	Limitations
1	<ul style="list-style-type: none"> Relatively flat or gently sloping terrain; Some distance away from N14 for reduced visual impact; and Some distance away from major residential area. 	<ul style="list-style-type: none"> Further away from proposed end of tunnel and waste rock dump and across N14, implying increased sludge delivery and haulage costs; and Some agricultural activity.
2	<ul style="list-style-type: none"> Gently sloping; and Unutilised area; would not impose on land uses according to knowledge of Study Team. 	<ul style="list-style-type: none"> Further away from proposed end of tunnel and waste rock dump and across N14, implying increased sludge delivery and haulage costs; Close to spruit and might therefore require additional storm water management and environmental approval; and Close to N14; unsightly and possible public resistance.
3	<ul style="list-style-type: none"> Closer to the end of the tunnel, implying reduced sludge delivery and return water costs. 	<ul style="list-style-type: none"> Close to N14 and nature reserve; unsightly and possible public resistance; and Small airport on site; might therefore be difficult to obtain land.
4	<ul style="list-style-type: none"> Very close to the end of the tunnel, implying reduced sludge delivery and return water costs. 	<ul style="list-style-type: none"> Bordering nature reserve; Steep and hilly terrain; and Close to Krugersdorp Aerodrome.

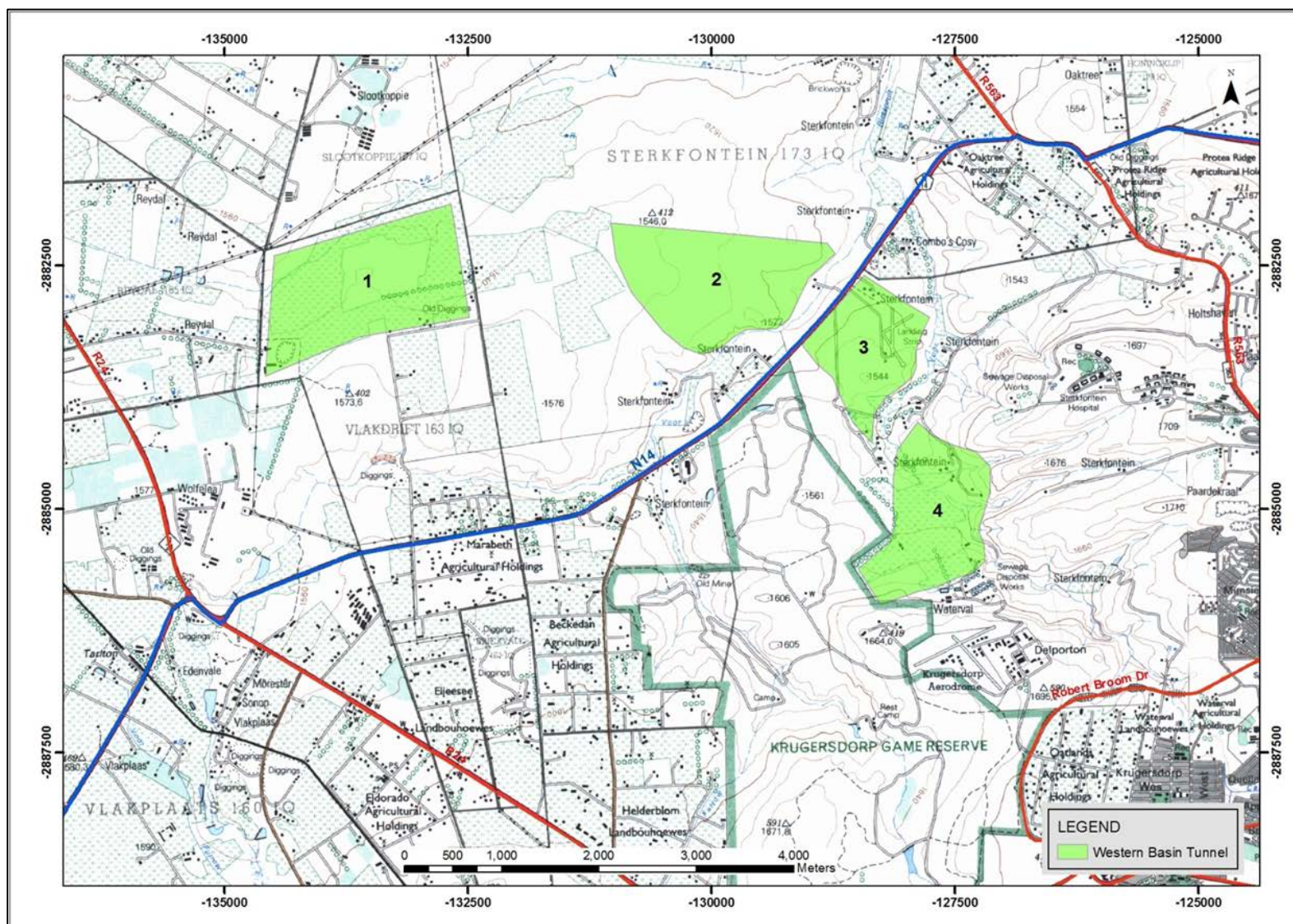


Figure 5.4: Proposed Western Basin Tunnel sites (topographical map)

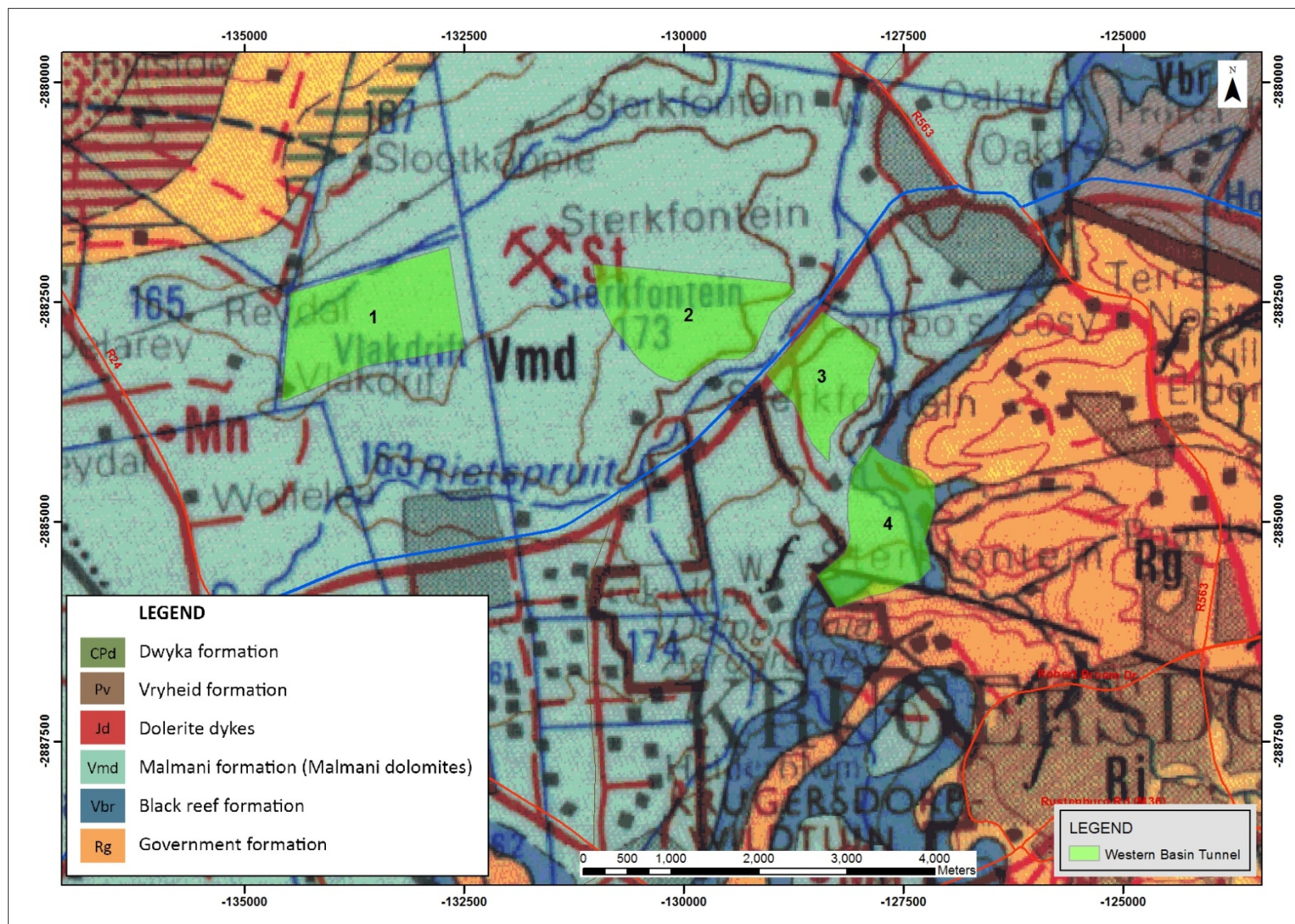


Figure 5.5: Proposed Western Basin Tunnel sites (geological map)

5.6.3 Central Basin disposal sites

The proposed sites for the Central Basin are indicated in **Figure 5.6**.

The underlying geology of the sites is indicated in **Figure 5.7**. The following characteristics of the underlying geology were noted:

Site 1: Underlain by rocks of the Vryheid formation, Dwyka group and Black Reef formation. The Black Reef formation consists mostly of Black Reef quartzite, but may also contain localised wads, carbonaceous shale and Basal conglomerates. The Dwyka group consists mostly of tillite. The Vryheid formation consists mostly of sandstone and mudrock, with layers of siltstone and small coal seams also occurring.

Site 2: Underlain by rocks of the Vryheid formation. The Vryheid formation consists mostly of sandstone and mudrock, with layers of siltstone and small coal seams also occurring.

Site 3: Underlain by rocks of the Vryheid formation and Dwyka group. The Dwyka group consists mostly of tillite. The Vryheid formation consists mostly of sandstone and mudrock, with layers of siltstone and small coal seams also occurring.

Site 4: Same as Site 3, but Dolerite dykes also occur towards the west.

Site 5 (Ergo site): Underlain by rocks of the Vryheid formation, Dwyka group, Malmani dolomites of the Malmani subgroup as well as Dolerite dykes. The Dwyka group consists mostly of tillite. The Vryheid formation consists mostly of sandstone and mudrock, with layers of siltstone and small coal seams also occurring.

The advantages and limitations of the proposed sites are listed in **Table 5.4**.

Table 5.4: Characteristics of proposed Central Basin sites

Site	Advantages	Limitations
1	<ul style="list-style-type: none"> Gently sloping terrain; Large unutilised area close or adjacent to existing tailings dam, therefore visual impact would be reduced; and Would not make use of prime property. 	<ul style="list-style-type: none"> Close to private airport, with associated bird strike issues for aircraft.
2	<ul style="list-style-type: none"> Gently sloping terrain; Large unutilised area close adjacent to existing tailings dam, therefore visual impact would be reduced; and Would not make use of prime property. 	<ul style="list-style-type: none"> Close to private airport, with associated bird strike issues for aircraft.
3	<ul style="list-style-type: none"> On top of existing tailings dam, so no new land would be used, which might be more environmentally acceptable; Visual impact greatly reduced; and Flat area for construction. 	<ul style="list-style-type: none"> Land use might be an issue, as there is the possibility of re-mining the tailings; and Stability might be an issue.

Site	Advantages	Limitations
4	<ul style="list-style-type: none"> Partially on existing tailings dam and would therefore use less new land; Visual impact greatly reduced; and Flat area. 	<ul style="list-style-type: none"> Power lines run through the site; Land use might be an issue, as there is the possibility of re-mining the tailings; and Close to spruit and might therefore require additional storm water management and environmental approval.
5 (Existing Ergo site)	<ul style="list-style-type: none"> Already a tailings facility; and No developments on the facility, so public approval would be more easily obtained. 	<ul style="list-style-type: none"> Same engineering as for other sites. Site would probably still need to be lined to prevent existing minerals being mobilised into the groundwater; Privately owned; there needs to be a clear-cut apportionment of environmental liabilities if this TSF is used for HDS disposal; and The long-term project would need to take over the costs of rehabilitation of the existing tailings facility, which would add to the costs to the project.
6	<ul style="list-style-type: none"> Gently sloping terrain; Large unutilised area close or adjacent to existing tailings dam, therefore visual impact would be reduced; and No residential developments nearby. 	<ul style="list-style-type: none"> Land use might be an issue as site may be set-aside for future residential development; and Close to watercourse, and might therefore require additional storm water management and environmental approval.





5.6.4 Central Basin Tunnel: Option 1 waste disposal sites

The proposed sites for the Central Basin Tunnel: Option 1 are indicated in **Figure 5.8**.

The underlying geology of the sites is indicated in **Figure 5.9**. The following characteristics of the underlying geology were noted:

Site 1: Underlain by Malmani dolomites of the Malmani subgroup.

Site 2: Same as Site 1.

Site 3: Underlain by rocks from the Klipriviersberg group. This group consists mostly of volcanic rocks of andesitic to basaltic composition, with tuffs and agglomerates also occurring.

Site 4: Same as Site 3.

The advantages and limitations of the proposed sites are listed in **Table 5.5**.

Table 5.5: Characteristics of proposed Central Basin Tunnel: Option 1 sites

Site	Advantages	Limitations
1	<ul style="list-style-type: none"> Closest to the end point of the proposed tunnel; Gently sloping terrain; and Some distance outside the city for reduced visual impact. 	<ul style="list-style-type: none"> Close to Kliprivier and another spruit/river; might be within the 1:50 year floodline; and Farming and irrigation are presently occurring on the site.
2	<ul style="list-style-type: none"> Close to end point of proposed tunnel; Gently sloping terrain; and Some distance outside the city for reduced visual impact. 	<ul style="list-style-type: none"> Close to N1; negative visual impact; and Farming and irrigation on the site.
3	<ul style="list-style-type: none"> Close to end point of proposed tunnel; and Gently sloping terrain. 	<ul style="list-style-type: none"> Located on a wetland; and Close to N1; negative visual impact.
4	<ul style="list-style-type: none"> Very close to waste rock dump. 	<ul style="list-style-type: none"> Steep and hilly terrain; Close to residential areas; negative visual impact; might attract public resistance; and Close to Klipriviersberg Nature Reserve.

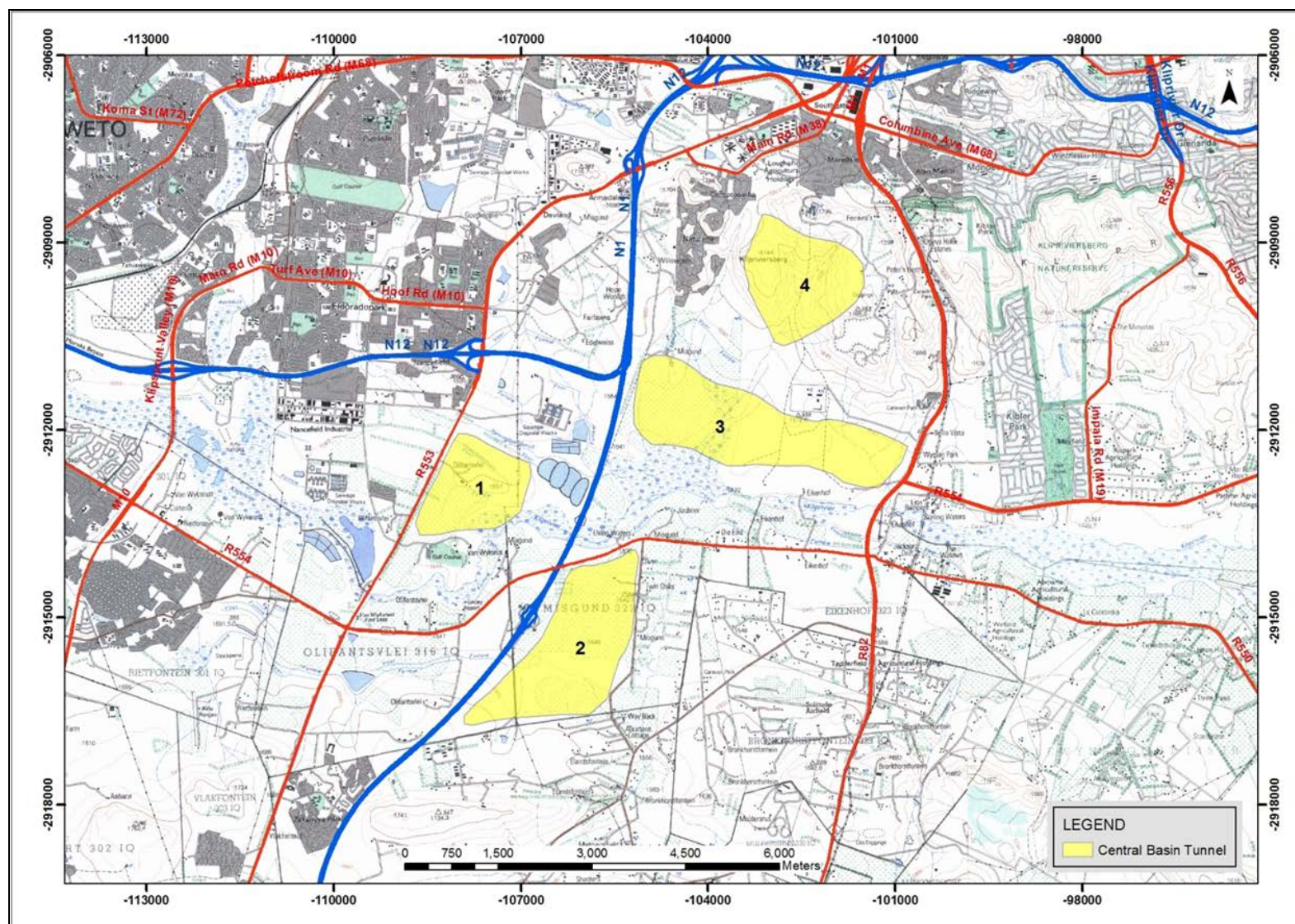


Figure 5.8: Proposed Central Basin Tunnel: Option 1 sites (topographical map)

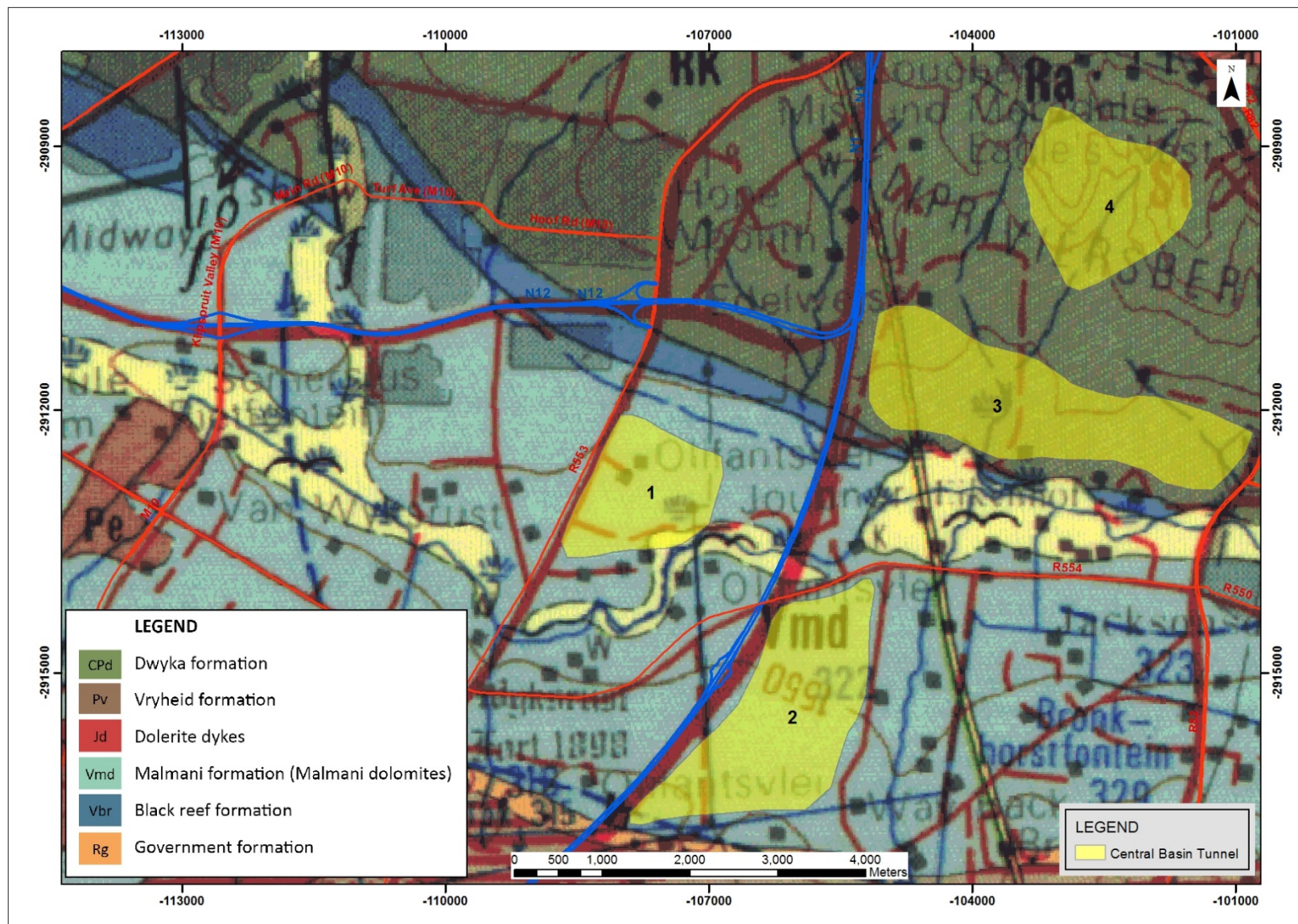


Figure 5.9: Proposed Central Basin Tunnel: Option 1 sites (geological map)

5.6.5 Central Basin Tunnel: Option 2 disposal sites

The proposed sites for the Central Basin Tunnel: Option 2 are indicated in **Figure 5.10**.

The underlying geology of the sites is indicated in **Figure 5.11**. The following characteristics of the underlying geology were noted:

Site 1: Underlain by Malmani dolomites of the Malmani subgroup as well as rocks of the Black Reef Formation. The Black Reef formation consists mostly of Black Reef quartzite, but may also contain localised wads, carbonaceous shale and Basal conglomerates.

Site 2: Underlain by Malmani dolomites of the Malmani subgroup as well as rocks of the Black Reef Formation and the Klipriviersberg group, with Dolerite dykes occurring. The Black Reef formation consists mostly of Black Reef quartzite, but may also contain localised wads, carbonaceous shale and Basal conglomerates. The Klipriviersberg group consists mostly of volcanic rocks of andesitic to basaltic composition, with tuffs and agglomerates also occurring.

Site 3: Same as Site 2.

The advantages and limitations of the proposed sites are listed in **Table 5.6**.

Table 5.6: Characteristics of proposed Central Basin Tunnel: Option 2 sites

Site	Advantages	Limitations
1	<ul style="list-style-type: none"> Closest to the end point of the proposed tunnel; Gently sloping terrain; and Smaller terrain. 	<ul style="list-style-type: none"> In the middle of a residential area; negative visual impact; might attract public resistance; and Close to main road and therefore has visual impact.
2	<ul style="list-style-type: none"> Gently sloping terrain; Large terrain available; and Outside city. 	<ul style="list-style-type: none"> Close to Kliprivier and another spruit/river; might be below 1:50 year floodline; and Farming and irrigation on the site.
3	<ul style="list-style-type: none"> Gently sloping terrain; Large terrain available; ad Outside city. 	<ul style="list-style-type: none"> Close to Kliprivier and another spruit/river; might be below 1:50 year floodline; and Farming and irrigation on the site.

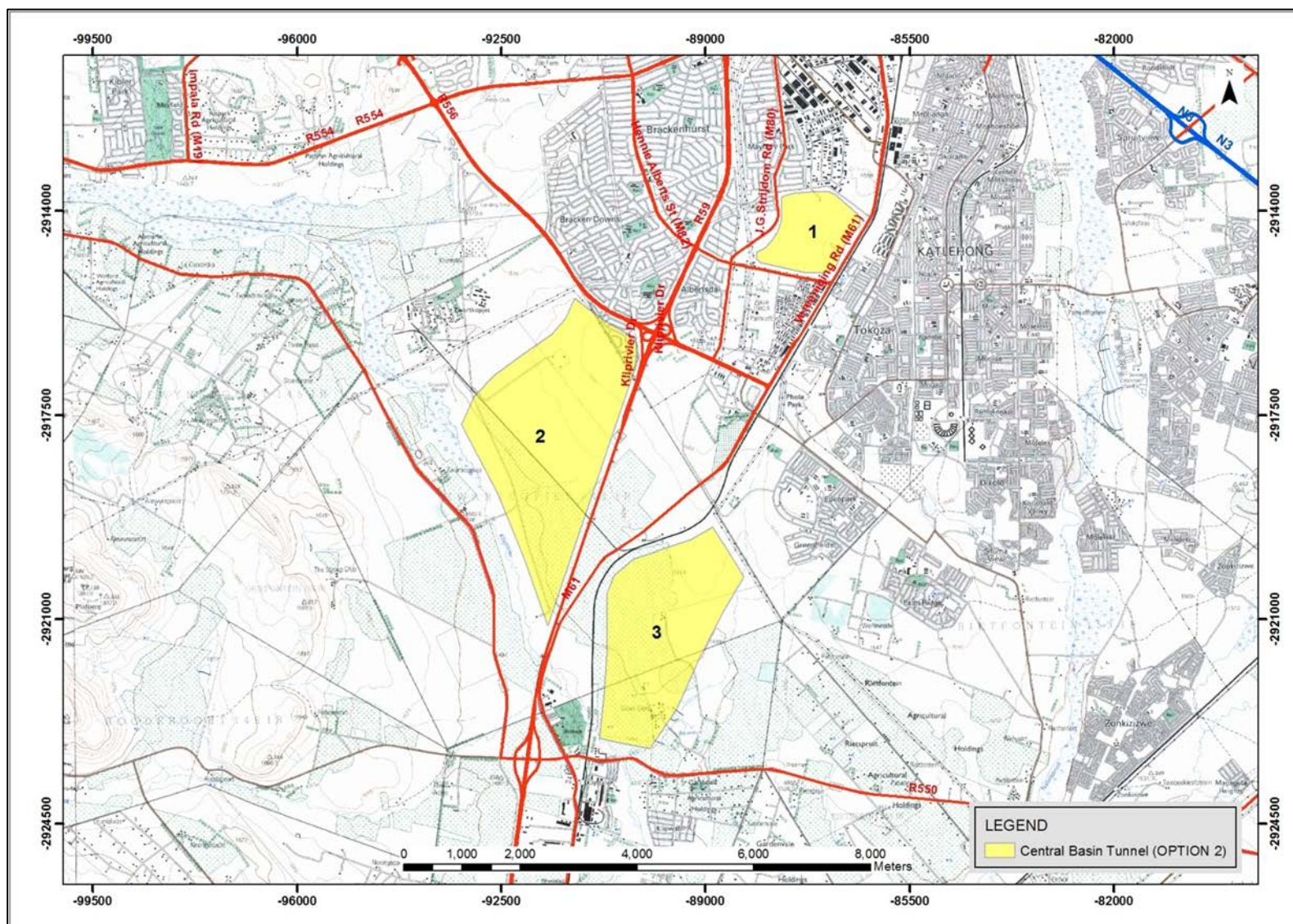


Figure 5.10: Proposed Central Basin Tunnel: Option 2 sites (topographical map)

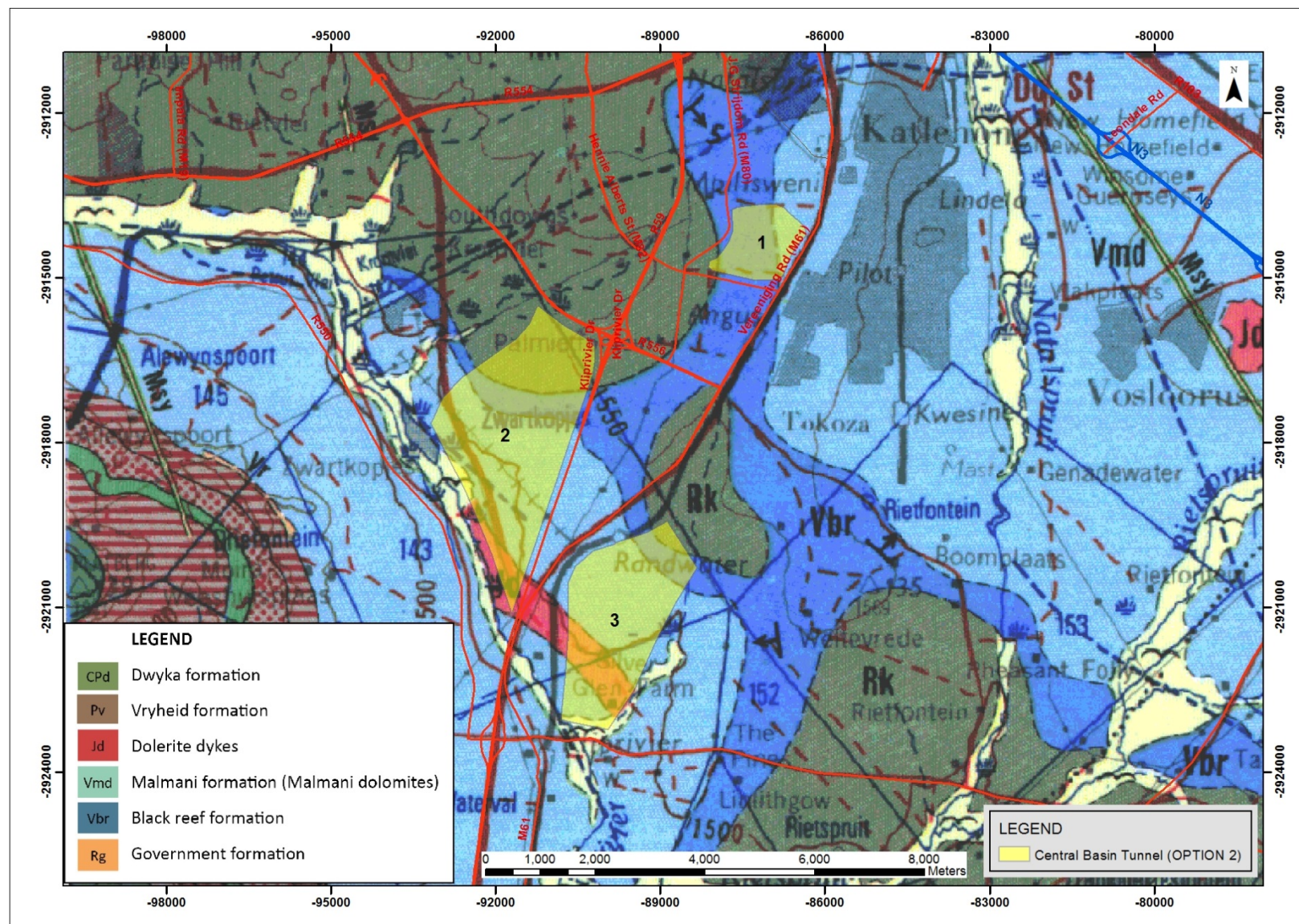


Figure 5.11: Proposed Central Basin Tunnel: Option 2 sites (geological map)

5.6.6 Eastern Basin disposal sites

The proposed sites for the Eastern Basin are indicated in **Figure 5.12**.

The underlying geology of the sites is indicated in **Figure 5.13**. The following characteristics of the underlying geology were noted:

Site 1: Underlain by rocks of the Vryheid formation and Dwyka group. The Dwyka group consists mostly of tillite. The Vryheid formation consists mostly of sandstone and mudrock, with layers of siltstone and small coal seams also occurring.

Site 2: Underlain by rocks of the Vryheid formation and Malmani dolomites of the Malmani subgroup. The Vryheid formation consists mostly of sandstone and mudrock, with layers of siltstone and small coal seams also occurring.

Site 3: Same as Site 1.

Site 4: Same as Site 1.

The advantages and limitations of the proposed sites are listed in **Table 5.7**.

Table 5.7: Characteristics of proposed Eastern Basin sites

Site	Advantages	Limitations
1	<ul style="list-style-type: none"> Large unutilised area adjacent to existing tailings dam; therefore visual impact would be reduced; Would not make use of prime property; and Gently sloping or flat. 	<ul style="list-style-type: none"> Some instability in the form of old mine-workings (on undermined area); and Wetland adjacent to the site, with associated environmental issues that might require extra construction and storm water diversion efforts.
2	<ul style="list-style-type: none"> On top of existing tailings dam; would not use any new land and might be more environmentally acceptable; Visual impact greatly reduced; and Flat area for construction. 	<ul style="list-style-type: none"> Land use might be an issue, as there is the possibility of re-mining the tailings; and Stability might be an issue (on undermined area).
3	<ul style="list-style-type: none"> Flat or gently sloping. 	<ul style="list-style-type: none"> Close to Aston Lake; Some agricultural activity on site; and Some instability in the form of old mine-workings (on undermined area).
4	<ul style="list-style-type: none"> Not undermined; and Flat or gently sloping. 	<ul style="list-style-type: none"> Close to residential area; and Some agricultural activity on site.

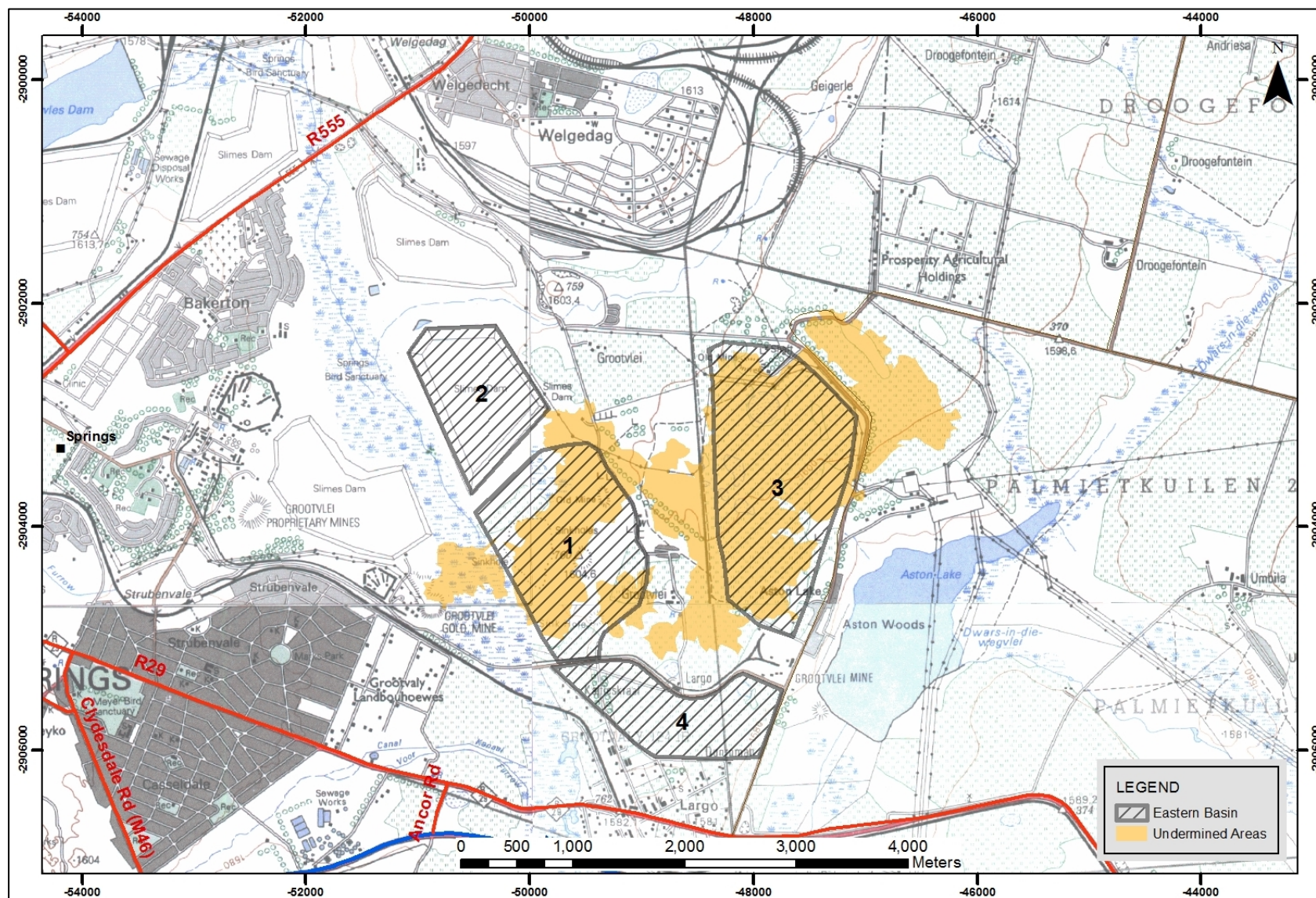


Figure 5.12: Proposed Eastern Basin Site (topographical map)

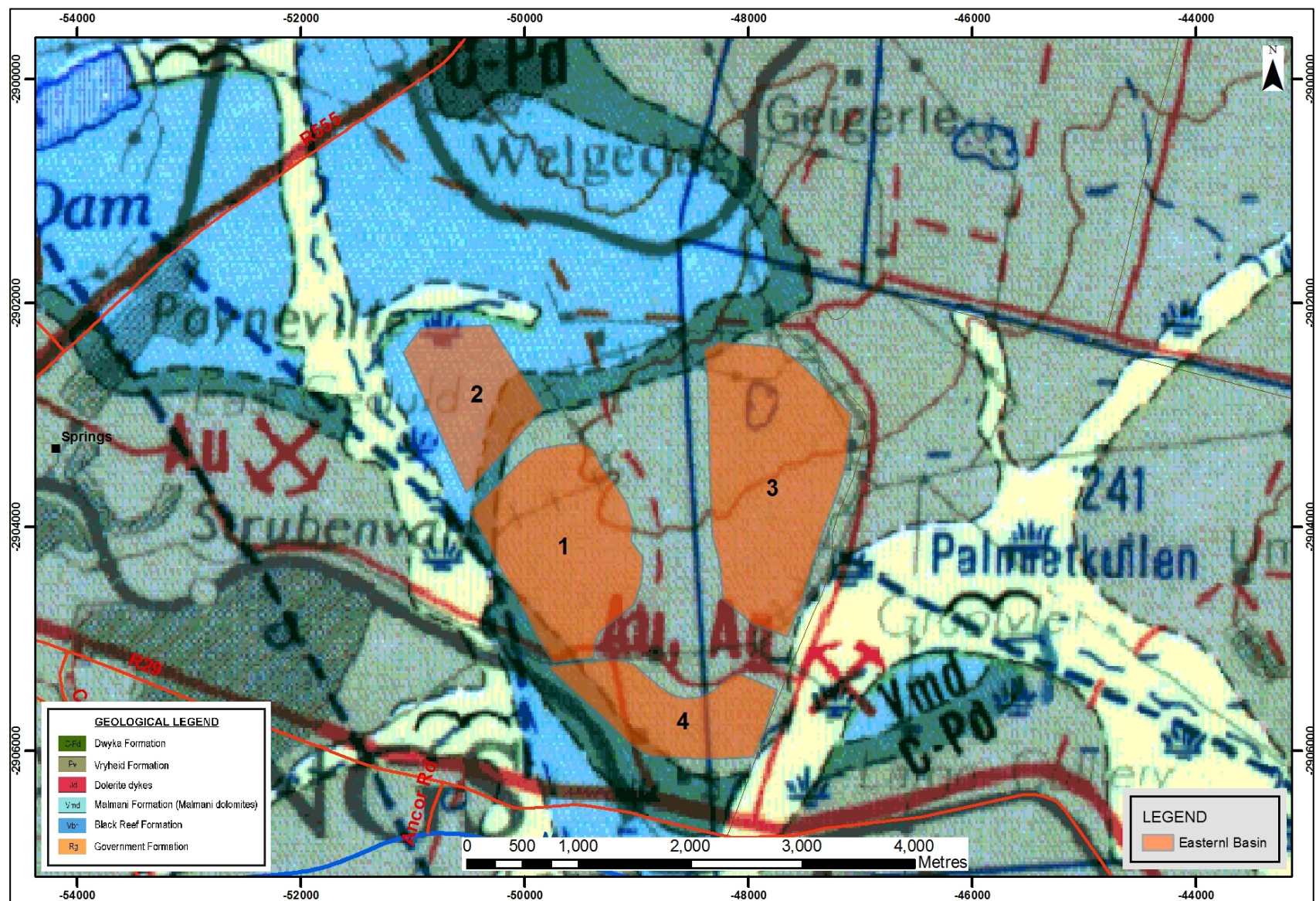


Figure 5.13: Proposed Eastern Basin Site (geological map)

5.6.7 Site ranking

The sites were ranked according to the number of potential fatal flaws, as defined in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998). The potential fatal flaws of the sites if they were to be used for waste disposal by landfill are:

1. Less than 3 000 m from the end of any airport runway or landing strip in the direct line of the flight path or within 500 m of an airport or airfield boundary. This is because landfills attract birds, creating a bird strike hazard for aircraft;
2. Areas below the 1:50 year flood line;
3. Areas in close proximity to significant water bodies;
4. Unstable areas, such as fault zones, seismic zones, dolomitic areas or shallow undermined areas;
5. Sensitive ecological and/or historical areas; nature reserves and areas with historical or cultural significance;
6. Catchment areas for important water sources;
7. Areas characterised by flat gradients, shallow or emergent groundwater, such as vleis, pans and springs;
8. Areas characterised by steep gradients, where slope stability might be an issue;
9. Areas of groundwater recharge, on account of topography and/or highly permeable soils;
10. Areas overlying or adjacent to important or potentially important aquifers;
11. Areas characterised by shallow bedrock with little soil cover;
12. Areas in close proximity to land uses that are incompatible with landfilling, including residential areas, nature reserves and cemeteries;
13. Areas where adequate buffer zones are not possible;
14. Areas of private land, as opposed to public land (expropriation asked);
15. Areas immediately upwind of a residential area in the prevailing wind direction(s);
16. Areas which, because of the title deeds and other constraints, can never be rezoned to permit a waste disposal facility;
17. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility (e.g. Rand Water, Eskom, etc.);
18. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost; and
19. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy.

Refer to Annexure A for a copy of Section 4 of the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998)

5.6.8 Site suitability ranking

Each potential site was considered and ranked according to the above criteria, with the objective of identifying the sites without fatal flaws. None of the sites were without any potential fatal flaws in terms of the DWA Minimum Requirements (1998). On the assumption that the facilities could be engineered so that the flaws are not fatal and that a licence could be obtained for the facility, the proposed sites were ranked according to the number of potential inherent fatal flaws. Final selection then took place based on the site with the lowest number of potential inherent fatal flaws and flaws that could most easily and effectively be engineered out.

a) Western Basin Site ranking

The site suitability ranking for the Western Basin sites is summarised in **Table 5.8**.

Table 5.8: Site suitability ranking for the Western Basin STI sites

Potential fatal flaw	Western Basin Site 1	Western Basin Site 2	Western Basin Site 3	Western Basin Site 4
1. Less than 3 000 m from the end of any airport runway or within 500 m of an airport or airfield boundary				
2. Areas below the 1:50 flood line*				
3. Areas in close proximity to significant water bodies				
4. Unstable areas	X	X		X
5. Sensitive ecological and/or historical areas				
6. Catchment areas for important water resources				
7. Areas characterised by flat gradients, shallow or emergent groundwater				
8. Areas characterised by steep gradients where stability of slopes might be an issue				
9. Areas of groundwater recharge, on account of topography or highly permeable soil				
10. Areas overlying or adjacent to important aquifers				
11. Areas characterised by shallow bedrock with little soil cover				
12. Areas in close proximity to land uses that are incompatible with landfilling		X	X	X
13. Areas where adequate buffer zones are not possible				
14. Areas of private land as opposed to public land (expropriation asked)				
15. Areas immediately upwind of a residential area in the prevailing wind direction			X	X

Potential fatal flaw	Western Basin Site 1	Western Basin Site 2	Western Basin Site 3	Western Basin Site 4
16. Areas which, because of the title deeds and other constraints, can never be rezoned to permit a waste disposal facility*	*	*	*	*
17. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility	X	X		
18. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost				
19. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy*	*	*	*	*
Total number of potential fatal flaws	2	3	2	3

* This work could only be done once the public participation phase is in progress. There is a risk of public upheaval if this is done at an earlier stage.

b) Western Basin Tunnel site ranking

The site suitability ranking for the Western Basin Tunnel sites is summarised in **Table 5.9**.

Table 5.9: Site suitability ranking for the Western Basin Tunnel sites

Potential fatal flaw	Western Basin Tunnel Site 1	Western Basin Tunnel Site 2	Western Basin Tunnel Site 3	Western Basin Tunnel Site 4
1. Less than 3 000 m from the end of any airport runway or within 500 m of an airport or airfield boundary			X	X
2. Areas below the 1:50 flood line*		*		
3. Areas in close proximity to significant water bodies		X		
4. Unstable areas	X	X	X	X
5. Sensitive ecological and/or historical areas			X	X
6. Catchment areas for important water resources				
7. Areas characterised by flat gradients, shallow or emergent groundwater				
8. Areas characterised by steep gradients where stability of slopes might be an issue				
9. Areas of groundwater recharge, on account of topography or highly permeable soil				
10. Areas overlying or adjacent to important aquifers				
11. Areas characterised by shallow bedrock with little soil cover				
12. Areas in close proximity to land uses that are			X	X

Potential fatal flaw	Western Basin Tunnel Site 1	Western Basin Tunnel Site 2	Western Basin Tunnel Site 3	Western Basin Tunnel Site 4
incompatible with landfilling				
13. Areas where adequate buffer zones are not possible				
14. Areas of private land as opposed to public land (expropriation asked)				
15. Areas immediately upwind of a residential area in the prevailing wind direction			X	X
16. Areas which, because of the title deeds and other constraints, can never be rezoned to permit a waste disposal facility*	*	*	*	*
17. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility			X	X
18. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost		X		X
19. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy				
Total number of potential fatal flaws	1	3	6	7

* This work could only be done once the public participation phase is in progress. There would be a risk of public upheaval if this were done earlier.

c) Central Basin Site ranking

The site suitability ranking for the Central Basin sites is summarised in **Table 5.10**.

Table 5.10: Site suitability ranking for the Central Basin sites

Potential fatal flaw	Central Basin Site 1	Central Basin Site 2	Central Basin Site 3	Central Basin Site 4	Central Basin Site 5 (Ergo)	Central Basin Site 6
1. Less than 3 000 m from the end of any airport runway or within 500 m of an airport or airfield boundary	X	X	X			
2. Areas below the 1:50 flood line*	*	*				*
3. Areas in close proximity to significant water bodies	X	X				X
4. Unstable areas						
5. Sensitive ecological and/or historical areas						
6. Catchment areas for important water resources						
7. Areas characterised by flat gradients,						

Potential fatal flaw	Central Basin Site 1	Central Basin Site 2	Central Basin Site 3	Central Basin Site 4	Central Basin Site 5 (Ergo)	Central Basin Site 6
shallow or emergent groundwater						
8. Areas characterised by steep gradients where stability of slopes might be an issue						
9. Areas of groundwater recharge, on account of topography or highly permeable soil						
10. Areas overlying or adjacent to important aquifers						
11. Areas characterised by shallow bedrock with little soil cover						
12. Areas in close proximity to land uses that are incompatible with landfilling						
13. Areas where adequate buffer zones are not possible						
14. Areas of private land as opposed to public land (expropriation asked)						
15. Areas immediately upwind of a residential area in the prevailing wind direction						
16. Areas which, because of the title deeds and other constraints, can never be rezoned to permit a waste disposal facility*	*	*	*	*	*	*
17. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility				X		
18. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost			X	X	X	
19. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy						
Total number of potential fatal flaws	2	2	2	2	1	1

* This work could only be done once the public participation phase is in progress. There would be a risk of public upheaval if this were done earlier.

d) Central Basin Tunnel: Option 1 site ranking

The site suitability ranking for the Central Basin Tunnel: Option 1 sites is summarised in **Table 5.11**.

Table 5.11: Site suitability ranking for the Central Basin Tunnel: Option 1 sites

Potential fatal flaw	Central Option 1 Site 1	Central Option 1 Site 2	Central Option 1 Site 3	Central Option 1 Site 4
1. Less than 3 000 m from the end of any airport runway or within 500 m of an airport or airfield boundary				
2. Areas below the 1:50 flood line*	*		*	
3. Areas in close proximity to significant water bodies	X		X	
4. Unstable areas	X	X		
5. Sensitive ecological and/or historical areas				
6. Catchment areas for important water resources				
7. Areas characterised by flat gradients, shallow or emergent groundwater				
8. Areas characterised by steep gradients where stability of slopes might be an issue				X
9. Areas of groundwater recharge, on account of topography or highly permeable soil				
10. Areas overlying or adjacent to important aquifers				
11. Areas characterised by shallow bedrock with little soil cover				
12. Areas in close proximity to land uses that are incompatible with landfilling				X
13. Areas where adequate buffer zones are not possible				
14. Areas of private land as opposed to public land (expropriation asked)				
15. Areas immediately upwind of a residential area in the prevailing wind direction				
16. Areas which, because of the title deeds and other constraints, can never be rezoned to permit a waste disposal facility*	*	*	*	*
17. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility				
18. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost				
19. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy				
Total number of potential fatal flaws	2	1	1	2

* This work could only be done once the public participation phase is in progress. There would be a risk of public upheaval if this were done earlier.

e) Central Basin Tunnel: Option 2 site ranking

The site suitability ranking for the Central Basin Tunnel: Option 2 sites is summarised in **Table 5.12**.

Table 5.12: Site Suitability Ranking for the Central Basin Tunnel: Option 2 sites

Potential fatal flaw	Central Option 2 Site 1	Central Option 2 Site 2	Central Option 2 Site 3
1. Less than 3 000 m from the end of any airport runway or within 500 m of an airport or airfield boundary			
2. Areas below the 1:50 flood line*	*		*
3. Areas in close proximity to significant water bodies	X		X
4. Unstable areas	X	X	X
5. Sensitive ecological and/or historical areas	X		
6. Catchment areas for important water resources			
7. Areas characterised by flat gradients, shallow or emergent groundwater			
8. Areas characterised by steep gradients where stability of slopes might be an issue			
9. Areas of groundwater recharge, on account of topography or highly permeable soil			
10. Areas overlying or adjacent to important aquifers			
11. Areas characterised by shallow bedrock with little soil cover			
12. Areas in close proximity to land uses that are incompatible with landfilling	X	X	
13. Areas where adequate buffer zones are not possible			
14. Areas immediately upwind of a residential area in the prevailing wind direction			
15. Areas which, because of the title deeds and other constraints, can never be rezoned to permit a waste disposal facility*	*	*	*
16. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility			
17. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost			
18. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy			
Total number of potential fatal flaws	4	2	2

* This work could only be done once the public participation phase is in progress. There would be a risk of public upheaval if this were done earlier.

f) Eastern Basin Site ranking

The site suitability ranking for the Eastern Basin sites is summarised in **Table 5.13**.

Table 5.13: Site suitability ranking for the Eastern Basin sites

Potential fatal flaw	Eastern Basin Site 1	Eastern Basin Site 2	Eastern Basin Site 3	Eastern Basin Site 4
1. Less than 3 000 m from the end of any airport runway or within 500 m of an airport or airfield boundary				
2. Areas below the 1:50 flood line*		*	*	*
3. Areas in close proximity to significant water bodies		X	X	
4. Unstable areas	X	X	X	
5. Sensitive ecological and/or historical areas.				
6. Catchment areas for important water resources				
7. Areas characterised by flat gradients, shallow or emergent groundwater				
8. Areas characterised by steep gradients where stability of slopes might be a problem				
9. Areas of ground water recharges on account of topography or highly permeable soil				
10. Areas overlying or adjacent to important aquifers				
11. Areas characterised by shallow bedrock with little soil cover				
12. Areas in close proximity to land-uses which are incompatible with landfilling	X	X		X
13. Areas where adequate buffer zones are not possible				
14. Areas immediately upwind of a residential area in the prevailing wind direction	X			X
15. Areas which, because of the title deeds and constraints, can never be rezoned to permit a waste disposal facility*	*	*	*	*
16. Areas over which servitudes are held that would prevent the establishment of a waste disposal facility.				
17. Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost				
18. Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy				
Total number of potential fatal flaws	3	3	2	2

* This work could only be done once the public participation phase is in progress. There would be a risk of public upheaval if this were done earlier.

5.6.9 Site selection conclusions

a) Western Basin sites

Sites 1, 2 and 4 are underlain by dolomite. Site 4 is the least favourable, because it is directly upwind of a residential area and would attract resistance from the public. Site 1 is very close to the Krugersdorp Game Reserve and has a power line running through the site. . The proximity of Site 3 to a cemetery might attract public resistance. . Site 2 has a railway and power line running through the site. Although the power line could be relocated, the relocation of the railway line would be a more costly exercise, unless this is no longer in use and there is no planned future use. It was therefore decided to continue with **Site 1** for this study. The issue of unstable ground conditions from dolomites could be addressed by lining the facility and thereby inhibiting the formation of sinkholes. Thorough geotechnical investigations would be necessary to determine the risk of sinkholes forming. This work will need to be done during the pre-feasibility or feasibility stage.

b) Western Basin Tunnel sites

Sites 3 and 4 are the closest to the end point of the proposed tunnel, but they are also least suitable in terms of potential fatal flaws. Site 3 is located on top of an existing airfield. It is also close to the Krugersdorp Game Reserve and adjacent to the N14 and would therefore possibly attract resistance from the public. Site 4 is located adjacent to the nature reserve and in close proximity to the aerodrome. Moreover, the terrain is steep and hilly. This disqualifies Site 4. Of the two remaining sites, **Site 1** was selected as it is further away from the nature reserve and the N14. Site 2 was disqualified as it has a spruit/river running through it. It should be noted that the establishment of a waste disposal facility on Site 1 would be more expensive, because it is the furthest away from the outlet of the proposed tunnel.

c) Central Basin sites

Of the proposed Central Basin sites, Site 3 is located on a tailings dam and Site 4 is partially on top of a tailings dam. The Ergo Mine tailings dam (Site 5) was also investigated. Sites 1 and 2 are located on the site of a small airport that is visible on aerial photos but not indicated on the topographical maps. Sites 1, 2 and 6 are close to a spruit and might have additional storm water management requirements. Site 6 is currently situated on agricultural land and falls outside the “Urban Edge”. There is a possibility that it might be included in the “Urban Edge” in the future. Due to the uncertainty regarding the use of tailings dams for the facility because of issues regarding the re-mining of the dams, potential ownership and liabilities (on sites 3, 4 and 5), it was decided that **Site 6** is the preferred site for this study because of the space available and the lower number of potential fatal flaws. Site 1 and Site 5 can be considered as possible alternatives should Site 6 be included in the “Urban Edge”.

d) Central Basin Tunnel: Option 1 sites

Sites 1 and 3 of the Central Basin Tunnel: Option 1 were discarded because they are situated on wetlands. Site 4 is situated on a hill close to the Kliprivierspruit Nature Reserve and adjacent residential areas and would have high visual impact. **Site 2** was therefore chosen for this study.

e) Central Basin Tunnel: Option 2 sites

Site 3 was chosen for the Central Basin Tunnel: Option 2. Site 1 is the closest to the end point of the proposed tunnel, but it is surrounded by residential areas and would attract significant public resistance. Site 2 is also very close to a residential area and the Kliprivier. Site 3 was therefore considered the best choice, although capital and operational costs would be higher due to its distance from the tunnel outlet.

f) Eastern Basin sites

Eastern Basin Site 1 is located on relatively flat land close to a wetland. The site also has some instability issues in the form of old mine-workings of the Largo Colliery, shallower than 20 m below the surface and sinkholes. Site 2 is located on an existing tailings dam where there would be problems related to the stability of the facility; there might also be issues related to ownership of the tailings and possible re-mining. The available area on Site 2 is also limited and won't be able to accommodate the sludge over a life of facility of 50 years. Although Site 3 is the largest it is also undermined by workings of the Largo Colliery to a depth shallower than 200 m. In light of the information provided above Site 1 to 3 have to be discarded leaving only **Site 4** as a possible location.

5.6.10 Capacity assessments

A capacity assessment was carried out for the selected site in each basin and also for the selected tunnel site for each tunnel option. This was done to ensure sufficient capacity and optimised operational costs. Assumptions had to be made regarding the final dry density of the slurry used to determine the capacity relationship. As no samples and test data is available at this stage assumptions on the dry density, solids percentages etc. had to be made using data from MWRP (Middelburg Water Reclamation Project).

a) Western Basin

The capacity assessment parameters and pertinent features in relation to the Western Basin disposal facility are shown in **Table 5.14**.

Table 5.14: Western Basin capacity assessment parameters

Parameter	Value
Dry Material	Metal-rich gypsum sludge
Sludge production rates (dry tonnages)	149.1 t/d
Life of facility	50 years
In-situ dry density of sludge @ 35% moisture	1.1 t/m ³
Waste rock in-situ dry density	2.0 t/m ³

Table 5.15: Pertinent features in relation to the Western Basin facility

Parameter	Value
Volume of waste rock required for starter wall (5 m high, 10 m crest; 1:4 outside slope, 1:2 inside)	369 800 m ³
Volume of waste rock required for complete impoundment (10 m crest; 1:4 outside slope, 1:2 inside)	601 120 m ³
Total volume of dry sludge contained at the end of Year 50	2 553 440 m ³
Annual waste rock requirement	25 000 t/a
Final footprint area of facility	528 000 m ²

The stage capacity curve for the sludge impoundment is shown in **Figure 5.14** and the stage capacity curve for the waste rock impoundment wall is shown in **Figure 5.15**. It was assumed that waste rock would be available free of charge, but loading and hauling have been allowed for.

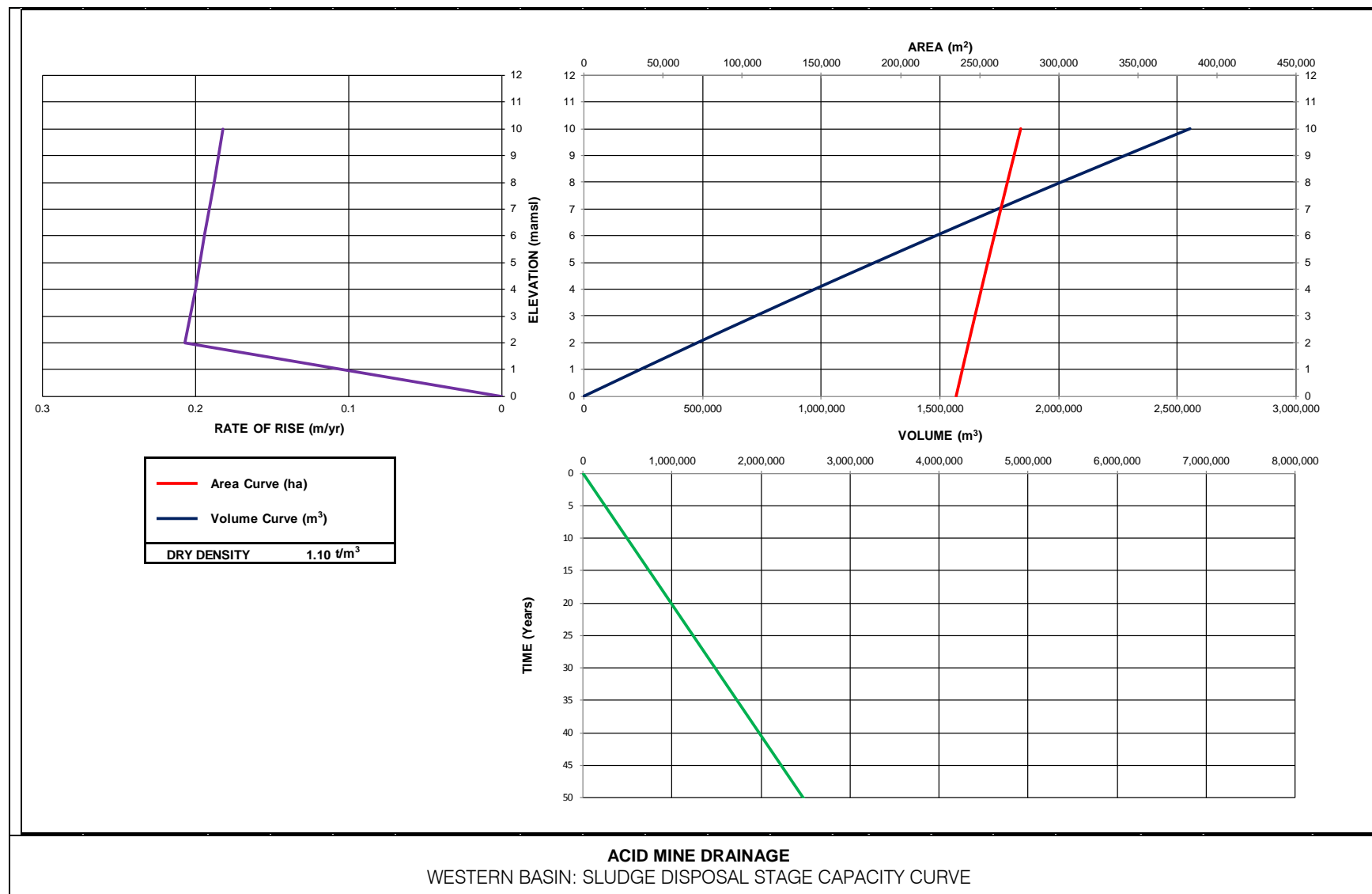


Figure 5.14: Western Basin facility stage capacity curve

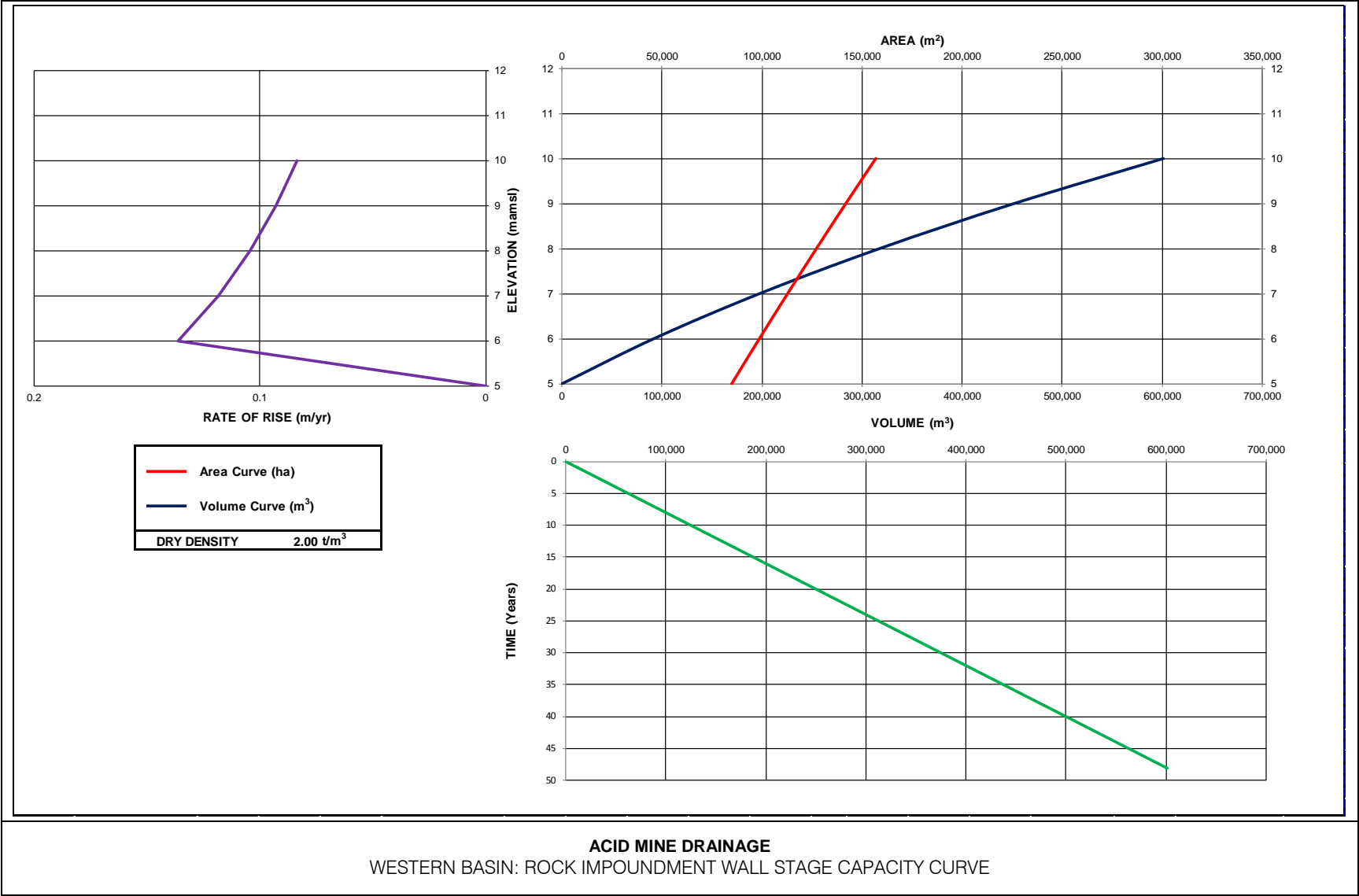


Figure 5.15: Western Basin waste rock impoundment wall stage capacity curve

b) Western Basin Tunnel

The capacity assessment parameters and pertinent features for the Western Basin Tunnel disposal facility are identical to those for the Western Basin indicated in **Table 5.14** and **Table 5.15**.

The stage capacity curve for the sludge impoundment and waste rock wall for the Western Basin Tunnel is identical to those for the Western Basin shown in **Figure 5.14** and **Figure 5.15**.

c) Central Basin

The capacity assessment parameters and pertinent features for the Central Basin disposal facility are shown in **Table 5.16** and **Table 5.17**.

Table 5.16: Central Basin capacity assessment parameters

Parameter	Value
Material	Metal-rich gypsum sludge
Sludge production rates (dry tonnages)	228.9 t/d
Life of facility	50 years
In-situ dry density of sludge @ 35% moisture	1.1 t/m ³
Waste rock in-situ dry density	2.0 t/m ³

Table 5.17: Pertinent features for the Central Basin facility

Parameter	Value
Volume of waste rock required for starter wall (5 m high, 10 m crest; 1:4 outside slope, 1:2 inside)	467 150 m ³
Volume of waste rock required for complete impoundment (10 m crest; 1:4 outside slope, 1:2 inside)	763 370 m ³
Total volume of dry sludge contained at the end of Year 50	3 872 940 m ³
Annual waste rock requirement	32 000 t/a
Final footprint area of facility	724 850 m ²

The stage capacity curve for the sludge impoundment is shown in **Figure 5.16** and the stage capacity curve for the waste rock impoundment wall is shown in **Figure 5.17**.

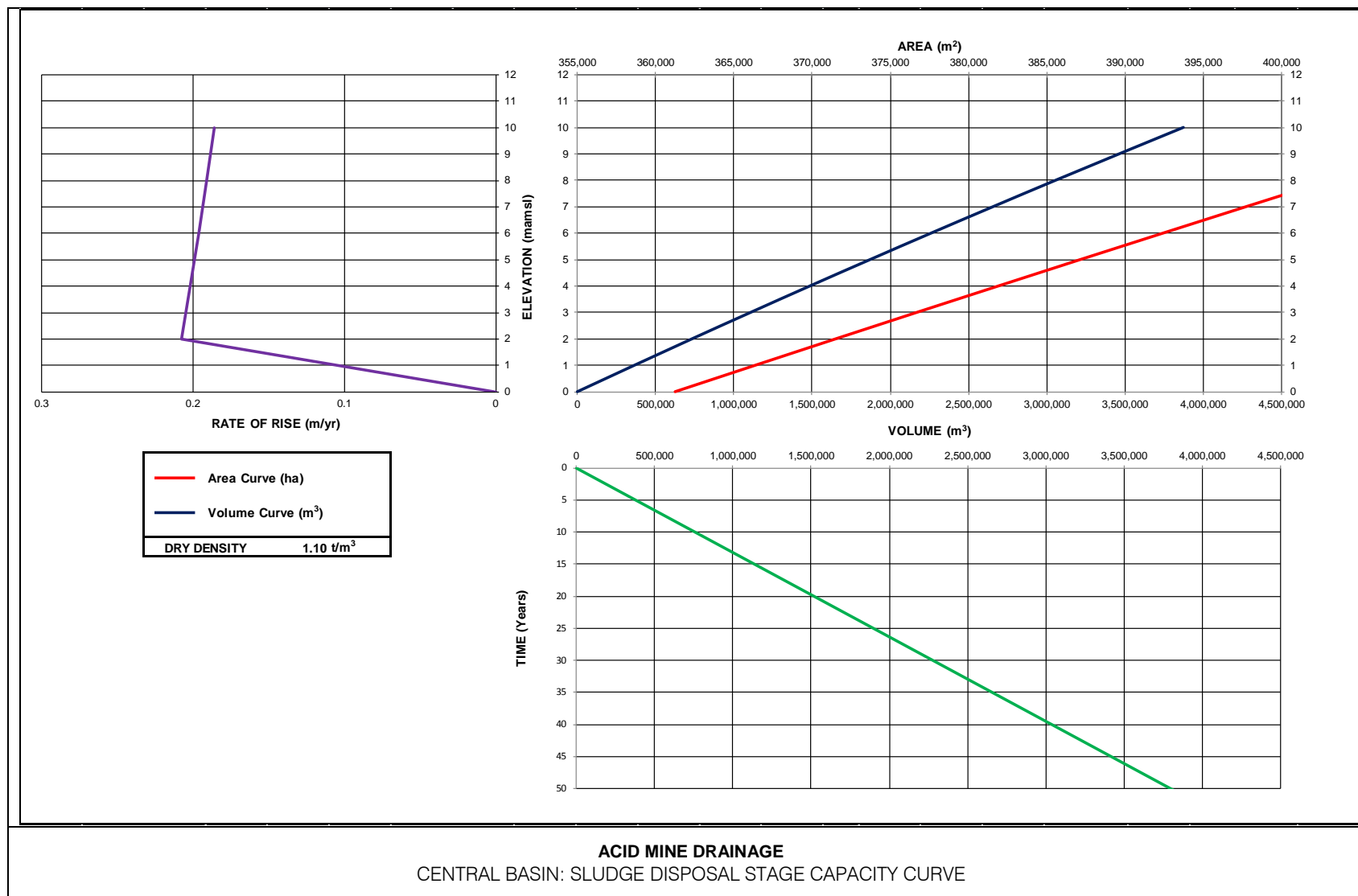


Figure 5.16: Central Basin facility stage capacity curve

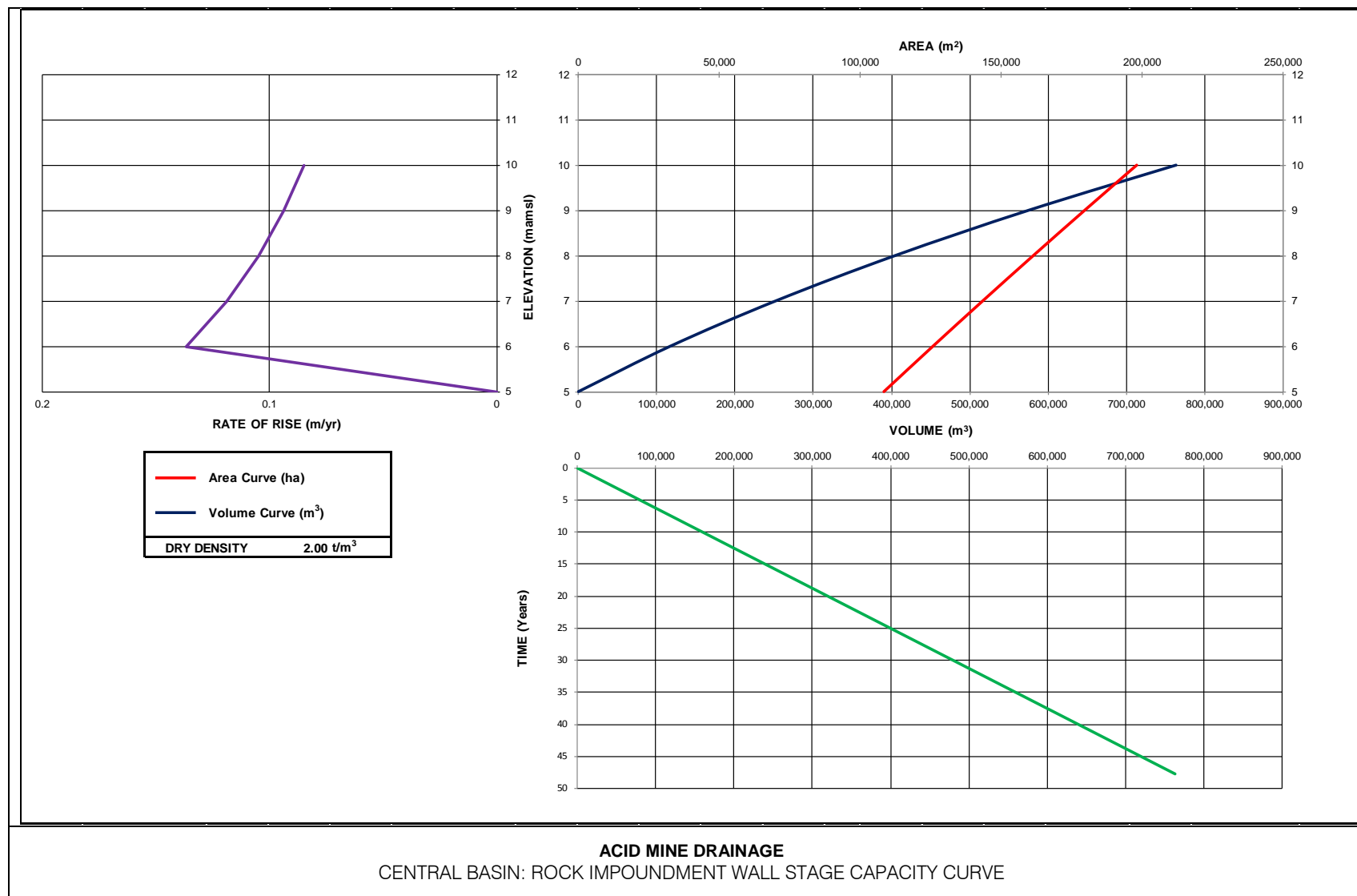


Figure 5.17: Central Basin waste rock impoundment wall stage capacity curve

d) Central Basin Tunnel: Option 1

The capacity assessment parameters and pertinent features for the Central Basin Tunnel: Option 1 disposal facility is identical to those of the Central Basin indicated in **Table 5.16** and **Table 5.17**.

The stage capacity curve for the sludge impoundment and waste rock wall for the Central Basin Tunnel: Option 1 is identical to those for the Central Basin shown in **Figure 5.16** and **Figure 5.17**.

e) Central Basin Tunnel: Option 2

The capacity assessment parameters and pertinent features for the Central Basin Tunnel: Option 2 disposal facility is identical to those of the Central Basin indicated in **Table 5.16** and **Table 5.17**.

The stage capacity curve for the sludge impoundment and waste rock wall for the Central Basin Tunnel: Option 2 is identical to those for the Central Basin shown in **Figure 5.16** and **Figure 5.17**.

f) Eastern Basin

The capacity assessment parameters and pertinent features for the Eastern Basin disposal facility are shown in **Table 5.18** and **Table 5.19**.

Table 5.18: Eastern Basin capacity assessment parameters

Parameter	Value
Material	Metal-rich gypsum sludge
Sludge production rates (dry tonnages)	208.5 t/d
Life of facility	50 years
In-situ dry density of sludge @ 35% moisture	1.1 t/m ³
Waste rock in-situ dry density	2.0 t/m ³

Table 5.19: Pertinent features for the Eastern Basin facility

Parameter	Value
Volume of waste rock required for starter wall (5 m high, 10 m crest; 1:4 outside slope, 1:2 inside)	368 150 m ³
Volume of waste rock required for complete impoundment (10 m crest; 1:4 outside slope, 1:2 inside)	1 346 418 m ³
Total volume of dry sludge contained at the end of Year 50	3 459 205 m ³
Annual waste rock requirement	55 000 t/a
Final footprint area of facility	574 994 m ²

The stage capacity curve for the sludge impoundment is shown in **Figure 5.18** and the stage capacity curve for the waste rock impoundment wall is shown in **Figure 5.19**.

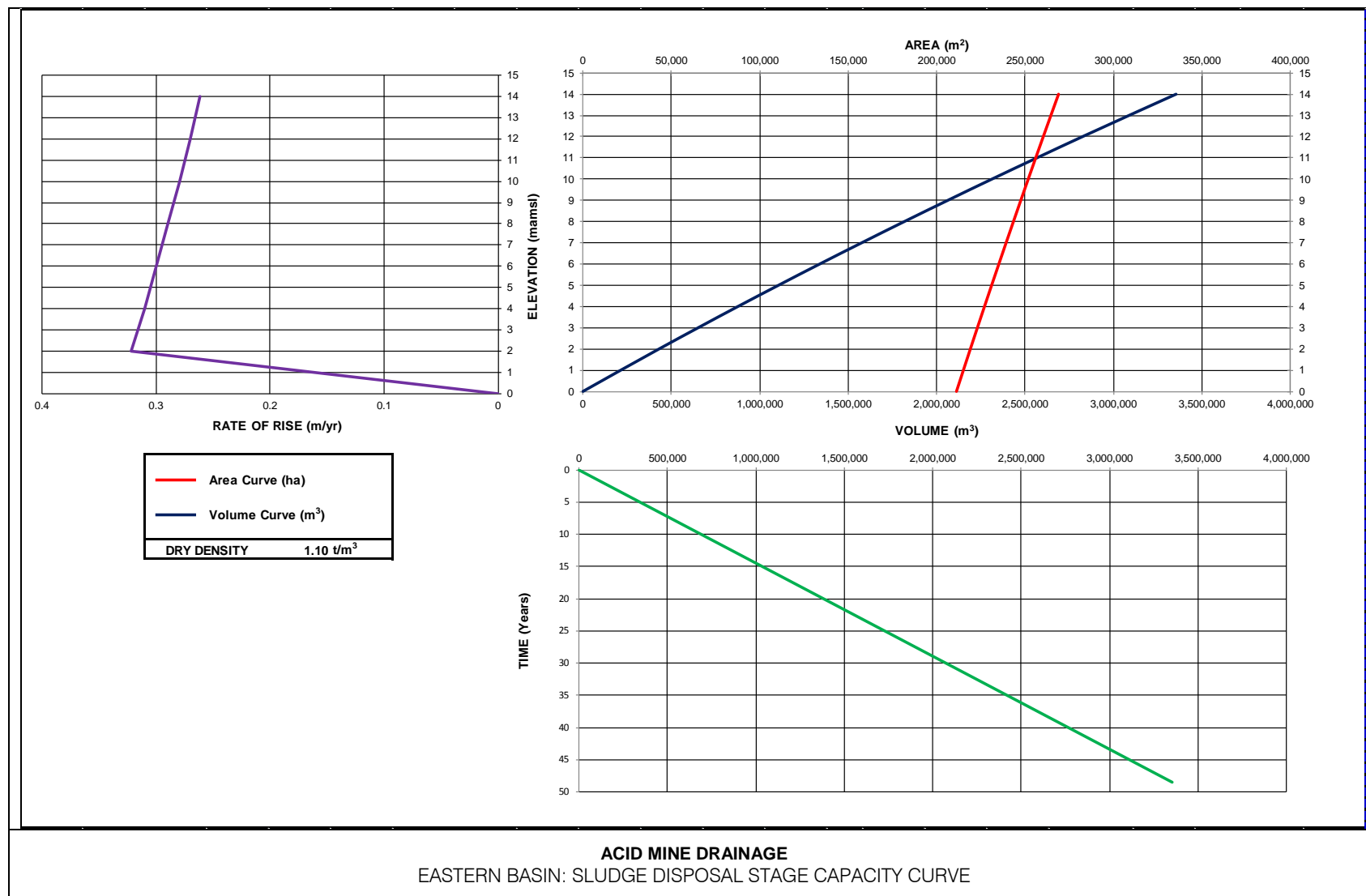


Figure 5.18: Eastern Basin facility stage capacity curve

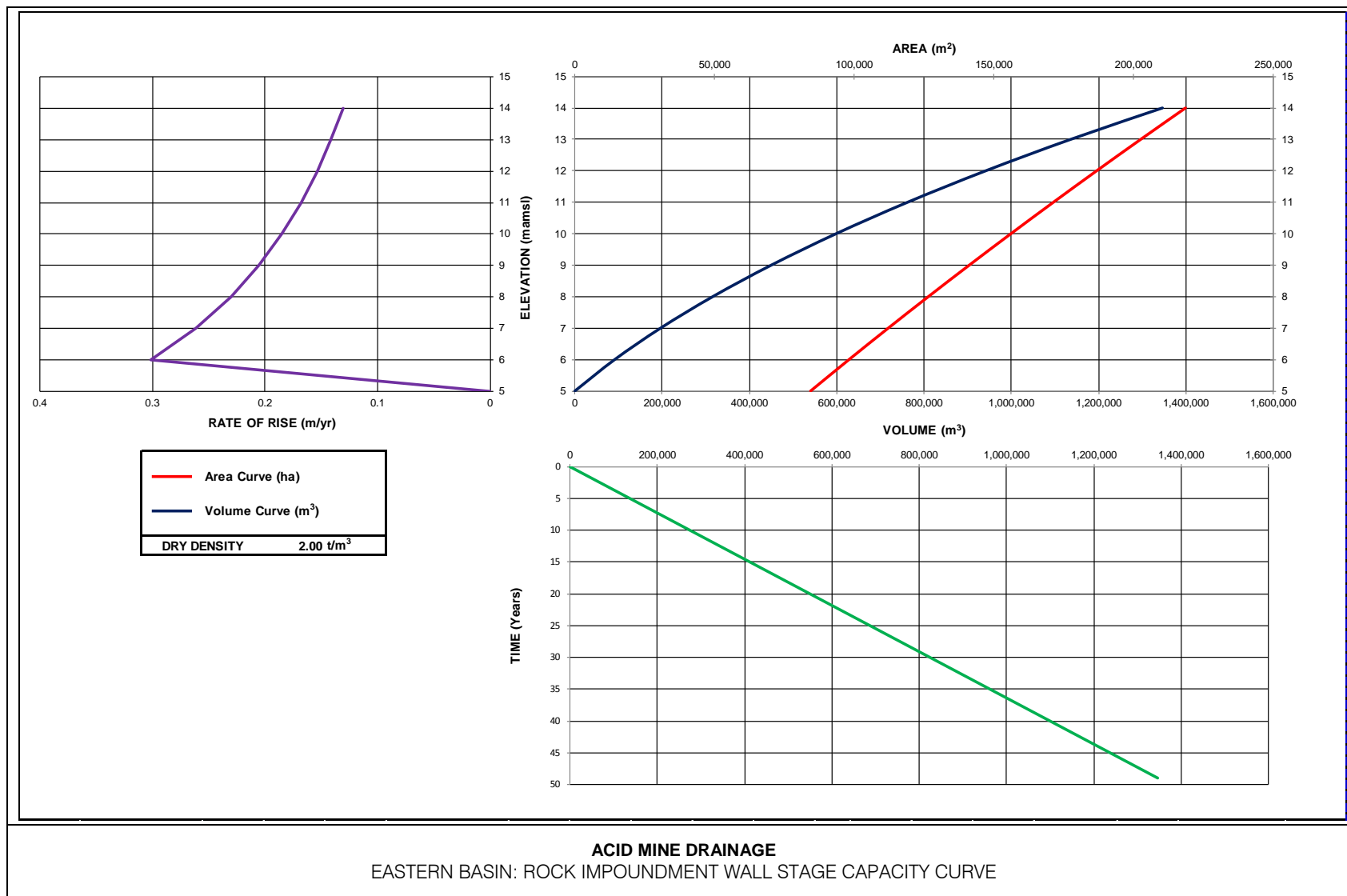


Figure 5.19: Eastern Basin waste rock impoundment wall stage capacity curve

5.6.11 Management of sludge disposal facilities

The sludge disposal facilities will be operated and managed in a similar manner to the way in which slurry disposal tailings facilities are operated and managed. Slurry is deposited from the perimeter using a spigot pipe discharge system. Based on experience at Grootvlei, the sludge is expected to beach away from the spigot pipes toward the centre, where a pool of supernatant and rain water collects. Proper deposition rotation will ensure that the pool is located at the centre of the facility. The water is decanted off the facility by means of a gravity penstock system constructed from stacked concrete penstock rings. The penstock is raised as the facility rises by stacking additional penstock rings. The penstock discharges into a return water dam, from where it is returned to the plant.

As the facility fills, the outer walls are continually raised to ensure sufficient freeboard. This is done to enable delayed capital expenditure.

Brine will be placed in a separate lined facility for evaporation, which will form part of the basin of the facility. The evaporation ponds will need to be extended as the amount of brine increases and this will need to be finalised in the detail design stage. Different water qualities will produce different sludge volumes

For proper operation and control, inspections are required at each shift, as well as daily, weekly, monthly, quarterly and annually. Each of these inspections will ensure that the facility conforms to the licence requirements. Annual reports will be prepared by third-party independent auditors and submitted to the licensing authorities.

It is anticipated that rainfall on the waste rock outer walls will form AMD, which will be collected and returned to the plant by means of the return water facility.

5.6.12 Closure of disposal facilities

Because the facilities will be constructed using the downstream method, closure can only happen once the facility is de-commissioned. The surface of the facility, as well as the outer walls, need to be isolated from the environment by sealing the waste HDS with plastic covers and the outer walls with clay and topsoil to prevent any further ingress of pollutants into the environment.

Post-closure monitoring and inspections will have to continue indefinitely to ensure that there is no ingress of pollutants to the environment.

5.7 Brine handling

Final brine treatment or brine storage is required to manage the concentrated stream of mainly monovalent species that cannot be precipitated. The main technologies available for final brine treatment are:

- Evaporation pond;
- Mechanical evaporation and crystallisation;
- Freeze desalination and crystallisation.

The production of final brine should be avoided as far as possible to minimise the cost and environmental and legacy risks associated with brine management

5.7.1 Evaporation ponds

Evaporation ponds are widely used to store and manage brine or other effluent streams that are not viable for further treatment.

The main advantages of evaporation ponds are that the technology is simple and well established and has a low operating cost; the main disadvantages are that it has high capital costs and environmental risk and large areas of land are required that are not always available.

Evaporation ponds are only a viable option where the annual evaporation rate from the brine is significantly more than the annual rainfall rate. Note that brine evaporation rates are lower than fresh water evaporation rates (WRC Report, 2012).

5.7.2 Mechanical or thermal evaporation and crystallisation

Mechanical or thermal evaporation and crystallisation is also widely used for the treatment of brine. The main advantages of mechanical or thermal evaporation and crystallisation are the small footprint and a salt product that is produced instead of a liquid effluent. Moreover, the condensate can be recovered as product water to increase the overall recovery. The main disadvantages are the high capital and operating costs; the energy-intensive nature of the process; and the fact that the final salt still needs to be disposed of at an additional cost as its level of purity is not suitable for reuse.

5.7.3 Freeze desalination and crystallisation

Freeze desalination is a novel process for the desalination of highly saline waters to produce fresh water and salts. Although there are no full-scale references in South Africa yet, this technology shows promise as an alternative to mechanical evaporation and crystallisation. This technology is the opposite of evaporation in the sense that water is purified by ice formation rather than steam formation. By using this technology, clean water as well as pure salt can be recovered from brine streams, significantly reducing the highly saline effluent

volumes. The main advantages of freeze desalination over evaporative crystallisation are the lower energy demands, reduced corrosion at low operating temperature and reduced risk of scaling. Freeze desalination and crystallisation can at this stage only be classified as a laboratory-scale process.

5.7.4 Co-disposal with sludge residues

Where disposal of dewatered sludge is practiced and the concentration and recovery of the sludge components can be optimised, it may be possible to generate a small enough quantity of monovalent-based brine that the entire brine stream could be co-disposed with the solid residues. One option is to simply increase the moisture content of the dewatered sludge with the brine for co-disposal, another is to do a brine wash of the sludge during the final dewatering step. ,

Co-disposal has the advantage of minimising the dual handling requirements for sludge and brine. However, due to the brine's mobility, it may result in a reclassification of the sludge and therefore require a more stringent liner system.

Co-disposal of brine with a pumped sludge, from which decant is returned to the water treatment plant, is not feasible due to the recycled brine's negative impact on the water treatment plant. Since the Reference Project assumes disposal of a liquid sludge and return of a decant stream, the co-disposal of brine with sludge is not seen as a viable option for the Reference Project.

5.7.5 Co-disposal with mine residues

Instead of co-disposal of the brine with the sludge residues, it may be possible to transport the small volume of brine for disposal to alternative mine residue disposal facilities. The relatively small load of monovalent salts should not have a material detrimental environmental impact when co-disposed with the sludge residues under controlled conditions, or when disposed to alternative mine residue disposal facilities under controlled conditions. However, if this option is implemented, care should be taken to ensure that the salts contained in the brine and mine residues does not leach and contaminate the ground or surface water resources.

5.7.6 Discharge of monovalent brine to receiving watercourse under controlled conditions

It may be possible to generate monovalent brine that is acceptable for discharge to the watercourse without the sodium and chloride levels posing a material detrimental impact, while still maintaining the resource quality objectives of the receiving water. This would depend on the practical monovalent salt loads generated by the individual basins and the processes applied to remove other salt and metal components.

The option of brine storage during normal times, with controlled release during high flow or flood times, when dilution capacity is available, can also be investigated.

5.7.7 Recommendation

Because of the low risk associated with evaporation ponds, it is recommended that this option be used for brine disposal. This is covered in more detail in DWA AMD FS 2013, Study Report No. 6: “**Concept Design**”.

6 IMPLICATIONS IF RESIDUES ARE RECLASSIFIED

6.1 Potential for reclassification

This study is based on the sludge from the Reference Project being classified as a general waste in terms of the DWA Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste – Third Edition 2005 (DWAF, 2005); however, recent (not promulgated) draft waste classification management regulations (DEA, 2012), when in use by the Department of Environmental Affairs, might result in the sludge being classified as hazardous. This section discusses the issues associated with such reclassification.

On the first level ('Waste Level 1'), general and hazardous waste would be distinguished based on the classification thereof, with hazardous waste being assigned the prefix "H", and general waste the prefix "G" (DEA, 2010). Hazardous waste is waste that has the potential, even in low concentrations, to have a significant adverse effect on public health and the environment because of its inherent toxicological, chemical and physical characteristics. The term General waste is applied to waste that does not pose a significant threat to public health or the environment. At Levels 2 and 3, Major Waste Types and Specific Waste Types are then respectively identified and corresponding codes assigned. Subject to sub-regulation (2), all waste generators must ensure that the wastes they generate are classified in accordance with SANS 10234 (2008).

The Level 2 and 3 categories for general waste are based on specific types of waste expected, e.g. PETE plastic and tyres. However, the Level 2 and 3 categories for hazardous waste are based on the classification system of the Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste (DWAF, 1998) and accordingly the hazard classes of SANS 10228 (2010) and SANS 10234 (2008), thereby reflecting the hazardous characteristics of waste streams, rather than specific types of hazardous waste.

The parameters that would exceed the general limits include aluminium (Al), calcium (Ca), iron (Fe), magnesium (Mg) and manganese (Mn). In small quantities, these metals are essential to life, but become toxic when absorbed in excessive amounts. The hazardousness is expressed with respect to their eco-toxicity with acute and chronic exposure varying with source and target. For aquatic species, the time limits of acute and chronic exposure are one hour and four days, respectively; time limits are longer for humans (Smith, et.al, 1999).

6.2 Aspects relating to potential reclassification

6.2.1 Implications

The implications of the waste product being classified as hazardous are:

- Probable elimination of potential alternative disposal methods such as tailings co-disposal or underground disposal;

- The exclusion of most of the sites considered for a disposal facility on the basis of the underlying geology, their relative proximity to residential areas and amenities, or their location relative to water bodies;
- Long-term care of hazardous waste disposal sites after closure, which is much more onerous than for general wastes. The implications are that funds for long-term monitoring and site maintenance would need to be set aside during the operation of the facility, which in turn would significantly increase the water treatment and waste disposal costs.

6.2.2 Permitting

The permitting process for a hazardous landfill site is more onerous than for a general waste disposal site, which might prolong the time before construction and commissioning could commence.

6.2.3 Management

Management and supervisory staff would necessarily have to be more highly skilled for a hazardous landfill site than for a general waste disposal site. This would add to the cost of operation and closure of the facility.

6.2.4 Closure

It is highly unlikely that a closure certificate for a hazardous landfill would be obtainable. This would mean that the entity producing the sludge would have an indefinite liability and obligation to care for the facility.

6.2.5 Social issues

More vociferous public resistance to hazardous landfills could be expected, which would add to the time and cost of impact assessments and permitting and might even lead to the exclusion of certain potential sites. It is also anticipated that the waste-producing entity would have to address issues arising from the perceived ill effects of the hazardous waste site on the environment and persons.

7 COST ANALYSIS

The capital costs were estimated for the chosen waste disposal site at each proposed treatment plant location. The parameters used for the capital cost estimate for each site are listed in **Table 7.1**.

Table 7.1: Capital cost estimate parameters

Parameter	Western Basin	Western Basin Tunnel	Central Basin	Central Basin Tunnel: Option 1	Central Basin Tunnel: Option 2	Eastern Basin
Starting length	560 m	560 m	850 m	850 m	850 m	650 m
Starting width	420 m	420 m	425 m	425 m	425 m	325 m
Starter wall height	5 m	5 m	5 m	5 m	5 m	5 m
Starter wall inside slope (v:h)	1:2	1:2	1:2	1:2	1:2	1:2
Starter wall outside slope (v:h)	1:4	1:4	1:4	1:4	1:4	1:4
Starter wall crest width	10 m	10 m	10 m	10 m	10 m	10 m
Total waste rock haul distance	5 km	25 km	10 km	12 km	30 km	6 km
Land acquisition cost	R200 k/ha	R200 k/ha	R200 k/ha	R200 k/ha	R200 k/ha	R200 k/ha

The following components were used to estimate the respective capital costs for each facility:

- Site clearance;
- Starter wall;
- Liner in the basin lined according to lining required for an H:H facility. This was used as to estimate the maximum costs for disposal);
- Leakage detection sump(s) and pumps;
- Access roads;
- Storm water diversion channels and related infrastructure;
- Perimeter fence;
- Delivery pipe ring main with spigot discharge pipeline and hosing on the starter wall;
- Floating decant platform and access; and
- Decant barge, decant barge pumps and related infrastructure.

7.1 Basis of cost analysis: capital, operating and closure costs

For the construction (capital) costs, a schedule of quantity was developed for each site and this was priced using rates recently received for tenders for a similar type of work.

The following considerations were taken into account in estimating the conceptual capital costs:

- The haul distance from identified waste rock dumps near the areas were estimated. The availability and suitability of the rock dumps need to be determined during the feasibility stage;
- Delivery and return water pipelines and pumps are excluded;
- This is presently a conceptual study only to identify potential sites and costs. If the landfill option for HDS disposal is selected, then detailed topographical and geological surveys would be required. The conceptual cost is based on the assumption that all sites are flat;
- The cost of land was estimated by researching the cost of various empty lands and farms in the area and calculating the cost per hectare of the properties. The average cost per hectare was then obtained and rounded up; and
- Contingencies of 40% were added.

Operating costs were estimated using similar prices from a professional operator for tailings storage facilities. Raising the wall and extending the liner would be additional costs, for which the rates used for the construction estimate were used.

The following components were used to estimate the operational cost:

- Annual volumes of rock required for wall raises;
- Costs of loading, hauling, placing and covering waste rock;
- Extending the liner with every wall raise;
- Extending the decant barge walkway and pipes;
- Extending the perimeter spigot pipeline with each wall raise;
- Maintenance costs of the facility and piping etc.;
- Operating costs based on R4 per ton of waste disposed, which is typical for tailings disposal sites;
- Professional fees for facility monitoring and inspection; and
- Contingencies of 40% were added.

The operational cost estimate is limited by:

- Assumptions regarding haul distance from presumably suitable waste rock dumps in the areas, which would need to be confirmed during the feasibility design stage; and

- Assumptions regarding operating costs, maintenance costs and professional fees, which would need to be confirmed at the tender stage.

Similar to the capital cost estimate, a schedule of quantities for the closure costs was developed for each site and this was priced using the same construction rates.

The following considerations were taken into account in the closure cost estimates for the various facilities:

- Shaping of the side slopes to the required end profile;
- Placing topsoil over the side slopes;
- Planting grass and vegetation on side slopes;
- Cost of removal of existing infrastructure;
- Costs associated with continued monitoring up to 50 years after closure at R720 000 per year; and
- Contingencies of 40% were added.

The limitations associated with the closure cost estimates include:

- The regulations according to the DWA Minimum Requirements for encapsulation of the facility cannot be met, as the end product will not be trafficable.
- The period after closure during which monitoring and inspections will take place is estimated and would have to be confirmed.
- The costs associated with on-going inspections and monitoring are estimated and could vary.
- The possible revenue from reselling some of the pipes, machinery, valves etc. to scrapyards was not taken into consideration.

7.2 Basis of cost escalations

The operating costs and closure costs were not escalated for this report. This will be addressed in the Concept Design that will be done for the Reference Project. The costs are therefore reported in March 2012 base terms.

7.3 Capital cost estimate

The estimated capital costs for each site are provided in **Table 7.2**.

Table 7.2: Summary of capital cost estimates

Facility	Capital cost	Land purchase cost	Total
	Rand (million)		
Western Basin	268	14	282
Western Basin Tunnel	330	14	344
Central Basin	379	19	398
Central Basin Tunnel: Option 1	379	19	398
Central Basin Tunnel: Option 2	380	19	399
Eastern Basin	263	15	278

7.4 Operational cost estimate

The operational costs were estimated for each option on each selected site. The parameters used for the estimate for each site are listed in **Table 7.3**.

Table 7.3: Basis for operational cost estimates

Parameter	Western Basin	Western Basin Tunnel	Central Basin	Central Basin Tunnel: Option 1	Central Basin Tunnel: Option 2	Eastern Basin
Final land area required (ha)	53	53	73	73	73	58
Perimeter dimensions (m)	800x660	800x660	1 090x665	1 090x665	1 090x665	938x613
Waste rock required for complete impoundment including starter wall (million m ³)	1.00	1.00	1.2	1.2	1.2	1.7
Quantity of sludge retained (million m ³)	2.6	2.6	3.9	3.9	3.9	3.5
Final height	10 m	10 m	10 m	10 m	10 m	14 m
Waste rock impoundment wall inside slope (V:H)	1:2	1:2	1:2	1:2	1:2	1:2
Overall waste rock impoundment wall outside slope (V:H)	1:4	1:4	1:4	1:4	1:4	1:4
Rock wall crest width (m)	10	10	10	10	10	10
Rock haul distance (km)	5	25	10	12	30	6
Professional fees per year	R350 000	R350 000	R350 000	R350 000	R350 000	R350 000
Operating costs (R million per year)	0.2	0.2	0.3	0.3	0.3	0.3
Maintenance costs	20% of capital costs of piping and mechanical/year (excluding land acquisition costs)					

The final land areas in **Table 7.3** are significantly larger than the starting areas (the initial parameters at the start of construction) determined in the Area Optimisation Curves. The areas would increase as the walls are raised, which is a phenomenon of downstream construction. Additional land would be required for infrastructure (access roads etc.). The values provided in **Table 7.3** are for the final land area required (i.e. the whole area enclosed within the perimeter fence, including the sludge disposal facility and related infrastructure).

The operational cost estimates for each site are shown in **Table 7.4**.

Table 7.4: Operational cost estimate summary

Facility	Average operational cost per year	Total for 50 years
	Rand (million)	
Western Basin	10.6	530
Western Basin Tunnel	12.7	635
Central Basin	13	650
Central Basin Tunnel: Option 1	13	650
Central Basin Tunnel: Option 2	15	750
Eastern Basin	14	700

7.5 Closure cost estimate

A summary of the closure costs for each site are provided in **Table 7.5**.

Table 7.5: Summary of closure cost estimates

Facility	Closure costs
	Rand (million)
Western Basin	65
Western Basin Tunnel	65
Central Basin	67
Central Basin Tunnel: Option 1	67
Central Basin Tunnel: Option 2	67
Eastern Basin	71

7.6 Total Cost Summary

The capital, operational and closure costs for each site are summarised in **Table 7.6**.

Table 7.6: Total Cost Summary for Waste Disposal Sites

Site	Capital costs (Year 0)	Operating costs over 50 years	Closure costs (Year 50)	Total costs
	Rand (million)			
Western Basin	282	530	65	877
Western Basin Tunnel	344	635	65	1044
Central Basin	398	650	67	1115
Central Basin Tunnel: Option 1	398	650	67	1115
Central Basin Tunnel: Option 2	399	750	67	1216
Eastern Basin	278	700	71	1049

The costs in **Table 7.6** should by no means be seen as the final costs for the capital, operating or closure costs of the identified options. These costs are merely a starting point for further investigation and should be regarded as preliminary costs. More in-depth cost estimating will take place during the Feasibility phase of the study when the Concept Design is prepared.

8 DISCUSSION

8.1 Residue Management Strategy

The recommendations made in this and subsequent reports of this study for the Reference Project are based on the residue management strategy, which is also in line with the definition of the Reference Project.

The Reference Project is the option which uses proven technologies, has minimum risk and which is used for financial modelling and budgeting. It is thus very conservative and has a very high expected rate of success, although it may not be the most effective from an environmental and commercial cost perspective.

The alternative innovative technologies discussed in section 2 and also in DWA AMD FS 2013, Study Report No. 5.4: “**Treatment Technology Options**”, show great potential in a number of treatment related aspects (*i.e.* lower CAPEX and OPEX, reduced residue volumes, ability to extract useable products, etc.). If products are generated which can be disseminated for commercial or other beneficial use, then this would reduce the environmental and commercial costs of disposal, positively influencing the project.

Taking into consideration the promise that alternative innovative technologies hold, and also keeping in mind that AMD management will have to continue for an indefinite period of time, it is imperative that research and development of these technologies form part of the LTS. The implementation of innovative technologies on pilot plants scale will provide an ideal opportunity for service providers to have their technologies tested and proven as suitable for the long-term, also from a residue management perspective. It is anticipated that pilot investigations will allow for the exploration and development of technologies with more sustainable by-product generation and management, with improved commercial and environmental costs. The quantity and nature of the final residue is therefore a key driver in assessing the innovative technologies to be implemented at pilot scale.

It is vital that reverse engineering be applied to find the most appropriate solution, *i.e.* start from the desired residue perspective and work towards the technologies that are able to achieve that. This will require development of the appropriate technologies and trade-offs to determine the solution with optimum environmental and commercial costs. During the procurement of the LTS, emphasis must be placed on the aspects related to minimising the hazardousness and quantities of residues going hand in hand with the development of the appropriate waste storage system if necessary, especially in the light of the high CAPEX and OPEX and the considerable areas required for the disposal facilities. Proposals from service providers that include options to co-dispose waste or to dispose of it into abandoned mine workings, should be evaluated without prejudice and if holistically it provides a better solution in the long-term than the Reference Project, it should be considered for implementation.

However, any alternative disposal methods must be very carefully considered. Such methods might seem like very attractive alternatives currently, but it is often not known what the impacts in the long-term could be. The disposal methods should not create future legacies which could have been avoided if a lower risk method could have been implemented, albeit at a higher cost. Another key aspect that should be considered during evaluation of proposals is the need to open up land for development and to reduce diffuse pollution, rather than increasing the number of residue facilities.

8.2 Sludge disposal

Various sites were identified for possible disposal of the HDS from each proposed AMD water treatment plant. These sites were located from aerial images. No on-the-ground investigations have been done at this stage, as land tenure has not yet been negotiated and public participation has not commenced. Detailed on-the-ground investigations will need to commence during or after public participation and environmental licensing. Topographical and geological maps were used in the assessment of the potential fatal flaws. The engineering out of any fatal flaws will need to be planned and executed during the Implementation Phase.

The analyses above are based on the HDS sludge being classified as a general waste, taken from prior reports regarding the STI. This assumption will have to be checked based on actual HDS samples from the chosen treatment technology and can only be confirmed once these samples are available. It is prudent to note, however, that the metal-rich sludge from BECSA's Middelburg Water Recycling Plant has been classified as a hazardous waste.

Another assumption used in the conceptual design and costing of the long-term HDS disposal facilities is that the metals will not be removed. Based on verbal reports on the sludge produced at the Grootvlei Mine treatment plant, this HDS is gelatinous due to the iron content. It is anticipated that the sludge will behave in the same manner as the Grootvlei sludge, in that it does not consolidate and gain any significant shear strength. In the absence of any samples, the behaviour of the material over time and its final in-situ density were estimated at this stage.

In identifying possible sites, the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998) document was used to determine the potential fatal flaws of each proposed site at a conceptual level. None of the identified sites were free of potential fatal flaws and some of the potential flaws would need to be addressed more closely once public participation and land acquisition are in process. It might be possible, by applying appropriate engineering practices, to reduce the impacts of some of the potential flaws (e.g. the influence of dolomites). The costing exercise progressed on this basis. It is important to note that it is not known whether this approach will be acceptable to the regulators. It is also noted that during the Implementation Phase design, detailed on-the-ground investigations and design of the waste facilities would need to be done. The design would have to comply

with all relevant legislation (such as the National Environmental Management, 1998 (Act No. 107 of 1998) and the National Water Act of 1998 (Act No. 36 of 1998) and the appropriate environmental management plans would have to be developed. The DWA's Best Practice Guidelines would have to be consulted at this stage to ensure that all legislative and other requirements are met.

If it is later found that it is not possible or permissible to engineer out the potential fatal flaws, it will be extremely challenging to locate sites on the Witwatersrand that would be suitable and acceptable for a landfill. If this is the case, it might mean that the Reference Project is flawed from a waste disposal perspective and alternatives would need to be considered. Potential alternatives could include:

- A treatment system where there is no production of HDS;
- Pre-treatment of the AMD to remove contaminants that create hazardous HDS; or
- An alternative HDS disposal system (underground disposal, for example, although this is not a popular solution at this stage).

Should sites be found that are not fatally flawed, then the cost of disposal would range from R285/m³ to R485/m³ in present terms. These are conceptual-level estimates, but can be used as the basis for determining the optimal solution to AMD treatment.

8.3 Brine disposal

The following possible options were identified for the disposal of brine from desalination of the neutralised water:

- Engineered lined evaporation ponds;
- Co-disposal with the sludge or alternatively disposal of liquid sludge and decant return;
- Marine disposal using a redundant pipeline belonging to Transnet, with the pipe being extended by a three to four kilometre-long diffuser into the sea;
- Deep well injection; or
- Disposal to rivers with dilution capacity.

These options all need further investigation and it has provisionally been assumed that brine will be disposed of in engineered lined evaporation ponds. This would result in the salts being retained in the lined storage facility and the liquids evaporating.

8.4 Conclusions and recommendations on sludge disposal

A number of sites were considered for each potential AMD treatment works location. All the sites that were considered have potential flaws, as listed in the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998). It is assumed, however, that any actual flaws could be engineered out. This aspect will need detailed attention during the Environmental Impact Assessment (EIA) and the Implementation Phase of this study.

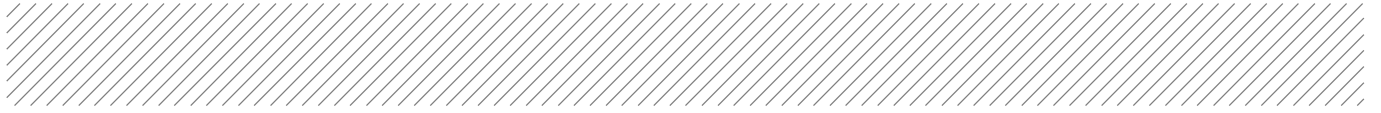
As a minimum, the following are required for the sites identified for the Reference Project:

- Detailed geotechnical and geophysical investigations of the selected sites. This will need to include investigations for dolomites, as well as depth to underground mining. All of these will need to be done in the design stage.;
- Hydrogeological investigations;
- Laboratory and, if possible, full-scale testing of the HDS for its geotechnical properties;
- Waste classification of the sludge and brines;
- Determination of the availability and suitability of the proposed waste rock sources for disposal if this option is finally considered;
- Water and monovalent salt balances;
- Confirmation of expected sludge production rates;
- Initiation of public participation and a land acquisition process; and
- Environmental management plans (EMPs) and licensing aspects.

It is further concluded that waste disposal on land should not be considered as the only option, as this will create further environmental and cost burdens due to the permanent nature of the disposal facility. It has been retained as the Reference Project, but there should be further attention to and investigation of alternative disposal systems during the Implementation Phase. Due to the onerous long-term management of the HDS landfill sites, there is a strong case for considering treatment options that do not create such quantities of waste, preferably those options that could create saleable products.

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Annexure A

Minimum Requirements for Waste Disposal by Landfill

Section 4

MINIMUM REQUIREMENTS FOR WASTE DISPOSAL BY LANDFILL



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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

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Section 4

SITE SELECTION

4.1 Introduction

The Minimum Requirements for site selection are summarised in Table 4, at the end of this Section.

Landfill site selection is the fundamental step in the development of a landfill. This step has far reaching economic, environmental and public acceptance implications. The landfill site selection process is only complete once the Department has found a site feasible on the basis of a feasibility study.

According to Section 24 of the Constitution: **‘everyone has the right to an environment that is not harmful to their health or well-being’**. The establishment and operation of waste disposal sites must therefore not violate the constitutional right of the communities living in the vicinity of the site.

The objectives of landfill site selection are as follows:

- **To ensure that the site to be developed is environmentally acceptable and that it provides for simple, cost-effective design which in turn provides for good operation.**
- **To ensure that, because it is environmentally acceptable, it is also socially acceptable.**

The landfill site selection process begins in response to an identified need for a disposal site. The classification system is then used to determine the class of landfill required to meet this need on the basis of the ‘givens’, i.e. the quality and

quantity of the waste and the potential for significant leachate generation. Once the class, and hence also the required land area and potential impact, of the proposed landfill has been determined, candidate sites can be identified.

At this point, DEAT (Province) must be contacted, and, if necessary, a Plan of Study for Scoping must be developed and approved (see Appendix 4.1). Then, the Interested and Affected Parties (IAPs) must be notified of the necessity for and the intention to develop a landfill in the area.

The IAPs are those people or groups concerned with or affected by the development of the proposed landfill. They may be the local authorities, the relevant government departments, NGOs, adjacent residents or farmers, a residential community, or the public at large. Democratically elected representatives of the public must be regarded as IAPs and would include local, provincial and national government forums.

Using primarily environmental and economic criteria, sufficient candidate sites must be identified to ensure the due consideration of alternatives. All the candidate landfill sites identified must be evaluated to determine the most acceptable sites. These must be documented and presented to the IAPs as a ‘Proposal’. Using a consultative process, the acceptability of the candidate landfill sites is reviewed and agreed. If necessary, the top sites may be subjected to a more detailed investigation to confirm their suitability.

A Feasibility Study, involving a preliminary

environmental impact assessment and geohydrological investigation, must then be carried out on the best site. This will determine whether the potential impact of the site is environmentally and socially acceptable. After this, the IAPs and communities must again be consulted for their input, and their acceptance of the proposed development must be confirmed and documented.

Should the site under consideration not prove feasible in terms of environmental acceptability or community acceptance, the next site is considered.

In the case of an operating landfill that is to be permitted, the Feasibility Study will determine whether the site should be permitted for ongoing operation or for closure. The IAPs must be consulted during the study, to obtain their input regarding the future of the landfill.

The process of landfill site selection is only completed when a site has been accepted as feasible by the IAPs, DEAT (Province) and the Department. Thereafter, detailed site investigations and the permitting process can commence.

4.2 Initiating the Public Participation Process

Public participation in waste management, as a whole, should be ongoing, and could involve education programmes, opportunities to be involved in policy making, and participation in alternative waste management programmes, such as recycling. This could be undertaken by government or NGOs.

Public involvement in the process of developing a specific landfill site begins once other waste management options have been addressed and the need for a waste disposal site has been established.

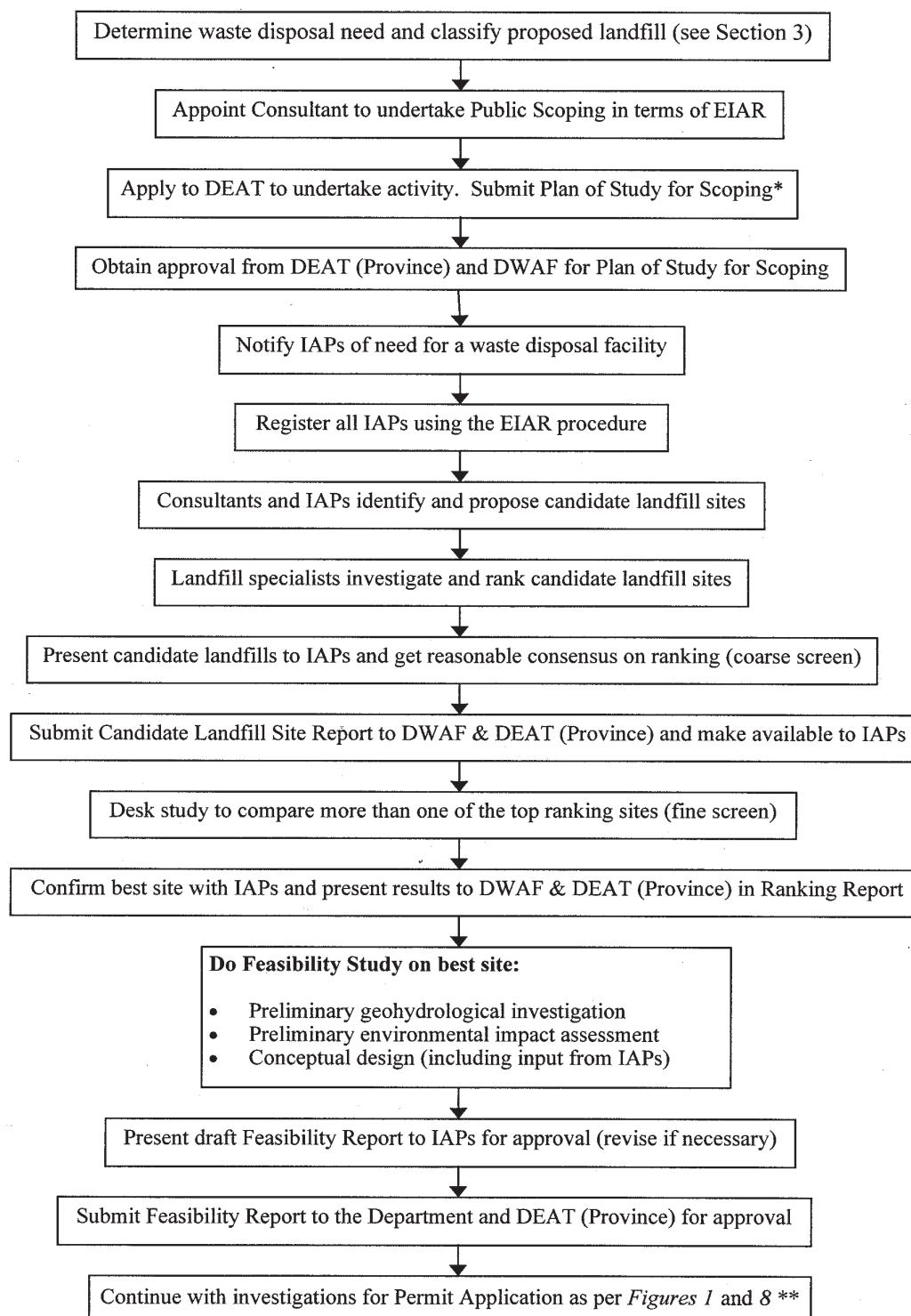
As waste disposal is an activity that may have a substantial detrimental effect on the environment, if not managed, it is subject to the Department of Environmental Affairs and Tourism's (DEAT) EIA Regulations (EIAR) [Ref: Government Gazette No. 18261, 5th September, 1997]. *Figure 6* indicates how the Minimum Requirements for public participation in the development of a landfill (see *Figure 1*) are integrated in the EIAR process (see Appendix 4.1).

In terms of the EIAR, once the class of the required landfill has been determined, a consultant must be appointed to undertake Public Scoping. An application form and a Plan of Study for Scoping must then be submitted to DEAT (Province) and the Department for approval. Once approval has been obtained, scoping can begin. The IAPs must be notified and informed of the need for a waste disposal facility. This is the first step in the public participation process that will take place throughout the development of the landfill (see Appendix 4.1).

The IAPs involved in the public participation process may change during the development of the landfill. For example, those who wish to be involved during site selection may be completely different from those who wish to be involved during the feasibility study, which focuses on a specific site.

IAPs should be contacted and registered in accordance with the EIAR (see Appendix 4.1). They must be informed of the need for a waste disposal site in the area and reminded that as waste generators they too are responsible for creating this need. Any alternative waste management solutions that have been explored should also be presented and discussed. The implications of the landfill classification should be explained. For example, the size of the operation will provide a

FIGURE 6
Determining Feasibility of a Candidate Landfill Site



* Although in the case of certain landfills Public Scoping and an EIA would not be required by DWAF, this may be required by the DEAT (Provinces).

** The EIA must be approved by DEAT (Provinces) in terms of the EIAR.

good indication of such changes as waste tonnages, infrastructure needed, vehicle movements, and land area.

The IAPs must be informed of the proposed site selection process and they must be given the opportunity to define the extent to which they wish to participate therein. A Representative IAP Liaison Committee (RILC) could be elected to liaise with the developer or the consultant.

At this stage, candidate landfill sites may be identified by the landfill consultants, as well as the IAPs.

4.3 Approach to Site Selection

Early considerations in site selection are to identify the size and the general location of the required site.

- **Size of the site.** When the site is classified, the size of the waste stream and hence the MRD is calculated (see Section 3). This calculation gives a good indication of the physical size of landfill and hence the area of land required.
- **General site location.** This is determined by the waste generation area(s) to be served. It is economically sound practice to establish the proposed facility as close to the generation area(s) as possible, with a view to minimising transport costs. Thus, the initial area of investigation is defined by the economic radius, which will vary depending on the existing or proposed mode of waste transport. Since the location of the site relative to the waste generation area(s) is an economic consideration rather than a Minimum Requirement, it is not addressed further.

The further phases involved in the approach to site selection are as follows:

- The elimination of all areas with associated Fatal Flaws (see Section 4.4)
- The identification of candidate sites, based on the site selection criteria provided in Section 4.5.
- The ranking of candidate sites
- The carrying out of a Feasibility Study on the best option(s).

4.4 Elimination of Areas with Inherent Fatal Flaws

It is a Minimum Requirement that no landfill site be developed in an area with an inherent Fatal Flaw. The following situations may represent Fatal Flaws in that they may prohibit the development of an environmentally or publicly acceptable waste disposal facility except at excessive cost:

- **3 000m from the end of any airport runway or landing strip in the direct line of the flight path and within 500m of an airport or airfield boundary.** This is because landfills attract birds, creating the danger of aircraft striking birds.
- **Areas below the 1 in 50 year flood line.** This eliminates wetlands, vleis, pans and flood plains, where water pollution would result from waste disposal.
- **Areas in close proximity to significant surface water bodies,** e.g. water courses or dams.
- **Unstable areas.** These could include fault

zones, seismic zones and dolomitic or karst areas where sinkholes and subsidence are likely.

- **Sensitive ecological and/or historical areas.** These include nature reserves and areas of ecological and cultural or historical significance.
- **Catchment areas for important water resources.** Although all sites ultimately fall within a catchment area, the size and sensitivity of the catchment may represent a Fatal Flaw, especially if it feeds a water resource.
- **Areas characterised by flat gradients, shallow or emergent ground water, e.g. vleis, pans and springs, where a sufficient unsaturated zone separating the waste body and the ground water would not be possible.**
- **Areas characterised by steep gradients, where stability of slopes could be problematic.**
- **Areas of ground water recharges on account of topography and/or highly permeable soils.**
- **Areas overlying or adjacent to important or potentially important aquifers** (see Appendix 4.2).
- **Areas characterised by shallow bedrock with little soil cover.** These are frequently also associated with steep slopes, which may be unsuitable.
- **Areas in close proximity to land-uses which are incompatible with landfilling.** Land-uses which are incompatible with landfilling would attract community resistance and would include residential

areas, nature reserves and cemeteries.

- **Areas where adequate buffer zones are not possible.** Buffer zones are discussed in Appendix 4.3.
- **Areas immediately upwind of a residential area in the prevailing wind direction(s).**
- **Areas which, because of title deeds and other constraints, can never be rezoned to permit a waste disposal facility.**
- **Areas over which servitudes are held that would prevent the establishment of a waste disposal facility; e.g. Rand Water, ESKOM or Road Department servitudes.**
- **Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost.**
- **Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy.**

4.5 Identifying Candidate Landfill Sites

All possible alternative sites must be considered before making a final choice. It is a Minimum Requirement that sufficient candidate sites be identified to ensure the due consideration of alternatives. This will include any site put forward by the IAPs.

In identifying candidate landfill sites, numerous economic, environmental and public acceptance criteria must be considered. These criteria inter-relate, as there are always economic implications when candidate sites are sub-optimal in terms of environmental and/or public acceptance

characteristics. Also, the public will usually not accept an environmentally unsuitable landfill site.

The distance of the landfill site from the waste generation area is an example of opposing economic and public acceptance criteria. While increased distance from residential areas may be more desirable to the public, there is a cost penalty associated with increased haul distances.

4.5.1 Economic criteria

Economic criteria relate to the cost of obtaining, developing and operating a site. They include the following considerations:

- The possible incorporation of the site into a regional waste disposal system, either immediately or in the future. This tends to make a site economically more attractive.
- The economies of scale. Larger sites are economically more attractive.
- The distance of the landfill from the waste generation areas. This is directly proportional to transport costs.
- The size of the landfill. In general, if it is to be economical, the landfill must cater for the disposal of the waste stream over at least the medium term to justify the capital expenditure.
- Access to the landfill site. This has cost, convenience and environmental implications, especially if roads have to be constructed.
- The availability of on-site soil to provide low cost cover material. Importation of cover increases operating costs. Furthermore, cover shortage may reduce site life.

- The quality of the on-site soil. Low permeability clayey soils on site will reduce the cost of containment liners and leachate control systems.
- Exposed or highly visible sites. High visibility will result in additional costs being incurred for screening.
- Land availability and/or acquisition costs. These are often dependent on present or future competitive land-uses, such as agriculture, residential or mining.
- Other miscellaneous economic or socio-economic issues. These might arise in particular instances, e.g. where the displacement of local inhabitants must be addressed.

4.5.2 Environmental criteria

Environmental criteria relate to the potential threat to the biotic and abiotic environment, particularly to water resources. They include the following considerations:

- The distance to ground or surface water. The greater this distance, the more suitable the site is in terms of lower potential for water pollution.
- The importance of ground or surface water as water resources. The greater the resource value of the water, the more sensitive the establishment of a landfill on account of the potential for water pollution (see Appendix 4.2).
- The depth of soil on the site. The greater the availability of soil, the more cost-effective it will be for the landfill to meet the Minimum Requirements for operation. The landfill will

thus be more acceptable in terms of cover material and therefore control of nuisances.

- The quality of on-site soil. Low permeability soils reduce pollutant migration and are therefore favoured.
- Valleys where temperature inversion could occur. This could promote the migration of landfill gas and odours into populated areas.
- The sensitivity of the receiving environment. The development of a site in a disturbed environment, such as derelict mining land, would be preferable to a development in a pristine environment.

4.5.3 Public acceptance criteria

Public acceptance criteria relate to such issues as the possible adverse impact on public health, quality of life, and local land and property values. They also relate to potential public resistance to the development of a landfill site. Failure to meet the public acceptance criteria may constitute a Fatal Flaw. The following are important considerations:

- The displacement of local inhabitants. This will usually arouse public resistance.
- Exposed sites with high visibility. These are less desirable than secluded or naturally screened sites.
- The sensitivity of the environment through which the access road(s) passes. The shorter the distance to the site through residential areas, the more acceptable the site.
- Prevailing wind directions. New landfills must be sited downwind of residential areas.
- The distance to the nearest residential area or

any other land-use which is incompatible with landfilling. The greater the distance from incompatible land-uses, the lower the risk of nuisance problems and hence resistance to the facility.

To protect the public from any adverse effects of a waste disposal operation, adequate buffer zones must be provided around landfills (see Appendix 4.3). Buffer zones are ‘set back distances’ or separations between the registered site boundary and residential developments. They may vary in width, depending on the classification of the landfill, the Site Specific Factors affecting the environmental impact, and the requirements of the Department and the IAPs. In general, no development may take place within a proclaimed buffer zone.

4.5.4 Critical factors

While not necessarily Fatal Flaws, economic, environmental and public acceptance criteria may be critical factors. This means that they may represent a severe constraint on the development or ongoing operation of a landfill.

A critical factor may, however, become a Fatal Flaw if it cannot be addressed to the satisfaction of the Department and/or if its presence should prevent the landfill from meeting a Minimum Requirement.

4.5.5 Procedure

By eliminating all areas with associated inherent fatal flaws, and taking note of all the criteria and critical factors listed in this section, a number of candidate landfill sites can be identified. These may include or be supplemented by candidate landfills identified by IAPs and should be presented on a map of suitable scale.

4.6 Ranking of Candidate Landfill Sites

Using the above criteria, the identified candidate landfill sites must now be technically evaluated and compared, to determine their acceptability.

In the early stages, when there are many candidate sites, a ‘coarse screening’ is carried out to eliminate the unsuitable sites and identify the top ranking sites. This exercise would initially be undertaken by specialists. The results will be presented to the IAPs in a report, the Candidate Landfill Site Report.

To do the coarse screening exercise, a discussion document and/or a matrix can be used.

Discussion document

A discussion document would discuss the facts pertaining to the candidate sites, using the main selection criteria, i.e. economic, environmental and public acceptance. The ranking of the sites would be motivated on the basis of these.

Site ranking matrix

A matrix can be developed with candidate sites on the one axis and selected criteria on the other (see *Figure 7*). The criteria should be appropriately weighted in order to reflect their relative importance. For example, size may be scored out of 20 whereas access may only be scored out of 5. In general, the matrix should be so designed that the following aspects are addressed:

- Environmental impact
- Safety risk (public safety, occupational health)
- Social impact

- Costs (acquisition, construction, operation and closure).

When using the matrix, each site is evaluated.

Scores are assigned for each criterion and added together to provide a total for each site. Thereafter, sites are ranked from the highest to the lowest.

*Candidate Landfill Site Report**

Once completed, the technical ranking must be presented to the IAPs, possibly through the RILC, for their input and for final ranking. Input may involve amendment of the ranking or the complete elimination of certain sites. The ranking will be presented in a draft Candidate Landfill Site Report.

Once the IAPs have confirmed the ranking, the Candidate Landfill Site Report, documenting the technical ranking exercise and IAP confirmation, must be submitted to the Department and to DEAT (Province) and made available to the public.

The Ranking Report

The top ranking sites themselves must now be compared to one another in a ‘fine screening’ exercise. In this exercise, a desk study of available information would be undertaken and a different, more detailed, matrix would probably be used for ranking. For example, each site could be ranked on an ABC system. For each criterion, the site rating best would receive an A, second best B, etc.

The results of this fine screening must be documented in a draft Ranking Report and confirmed with the IAPs.

When the top site is confirmed, the Ranking Report must be submitted to the Department and DEAT (Province) and be made available to the public.

* This report would be the equivalent of a draft of the EIAR Scoping Report.

FIGURE 7
Candidate Landfill Site Ranking Matrix

Candidate Site	Economic Criteria				Environmental Criteria					Public Acceptance Criteria				Total Score
	Distance	Size	Access	Etc.	Ground water	Surface water	Soil depth	Setting	Etc.	Distance	Visibility	Wind	Etc.	
Site 1														
Site 2														
Site 3														
Site n														

After this, the top ranking site is subjected to a more detailed investigation in the form of a Feasibility Study. This investigation is undertaken to confirm the environmental and public acceptability of the top ranking site.

4.7 The Feasibility Study and Report*

Input from the involved state departments may be desirable before subjecting the top ranking candidate landfill site to a more detailed investigation or the Feasibility Study.

The Feasibility Study is a Minimum Requirement for all **G:S**, **G:M**, **G:L**, **H:h** and **H:H** sites. Its aim is to confirm that the site has no Fatal Flaws. To do this, any critical factors must be identified and addressed to the satisfaction of the Department. The site must be proven to be both technically feasible and acceptable to the IAPs, before the Department will consider the site feasible for development.

In the case of an operating landfill that is to be permitted, the Feasibility Study will be used to determine the future of the landfill, i.e. whether it should be permitted for ongoing operation or for operation with a view to closure (see Section 4.7.8). It is a Minimum Requirement that the IAPs be consulted before this decision is taken.

The extent of the Feasibility Study and its presentation will depend on the class of landfill proposed, the physical complexity of the actual site, and the sensitivity of the receiving environment. Components of the study are provided below.

* This report would be the equivalent of the Scoping Report required by the EIAR.

4.7.1 Basic information

Certain information is necessary in order to provide background; this should include the following:

Landfill classification

In this section, all the information pertaining to the waste classification, the magnitude of the waste stream and the climatic and site water balances is presented. Based on this, the proposed landfill is classified, using the landfill classification system (see Section 3).

Indication of candidate landfill site procedure

In line with the IEM approach, more than one possible site should have been considered. In exceptional circumstances one site only can be considered, but these circumstances must be fully described and the exception must be motivated. In all other instances, the process of candidate landfill site identification and ranking must be described in the Feasibility Report, to the extent that the choice of the site under consideration is justified.

Site zoning

The current zoning of the site under consideration must be indicated and it must be guaranteed that it will be possible to zone it for waste disposal purposes.

Site description

The information provided in this section is usually based on both desk study information and observations from site visits. It should also include aspects forthcoming from the Preliminary Geohydrological Investigation and Environmental Impact Assessment, as well as any other information relevant to the development, design and operation of the site, e.g. topography,

drainage, aesthetics, wind direction, rainfall, existing vegetation, access, etc.

Permit Application Form

It is a Minimum Requirement that a Permit Application Form be completed and submitted in the Feasibility Report. This serves to inform the Department officially of the intention to develop a site. It is also a convenient means of presenting the information gathered in a standard format, for input into a waste disposal site registration system.

4.7.2 Preliminary Geohydrological Investigation

Normally, this is confined to the evaluation of existing information (maps and reports) and its confirmation in the field. Field confirmation will, in most instances, require testpits and, in certain instances, the drilling of a limited number of boreholes, and possibly blow yield tests. This investigation is considered the preliminary phase of the full investigation and is therefore carried out in accordance with the principles set out in Section 6. The information required is as follows:

Geology

This would include regional and local geology (stratigraphy and bedrock) as well as any structures (faults, dykes and lineations).

Soils

The soil on the site must be generally described and classified in terms of type, permeability, depth and volume available for cover material.

Borehole census or hydrocensus

All boreholes within a distance of one km from the site boundaries must be identified, with a view to recording ground water uses in the area. The purpose for which the water is used and borehole characteristics such as ground water levels, ground

water quality, borehole yields, borehole depth, abstraction rates, geological logs, casing/screen details and drilling date, should be included if available. The reliability of such data should also be indicated.

From the borehole census and from consideration of any surface water usage, or potential usage, an indication should be given of the importance of water resources in the vicinity of the landfill.

Ground water

An indication of the minimum depth to ground water in the vicinity of the site, the yield and the probable flow direction must be provided from the borehole census. The importance of the ground water as a resource must also be indicated, based on a preliminary aquifer classification (see Appendix 4.2). Again, the reliability of the information provided should be indicated.

The vulnerability of any aquifer and the risk of its possible pollution should be interpreted to provide an overall assessment of the ground water regime. These issues are discussed from a monitoring point of view in the *Minimum Requirements for Monitoring at Waste Management Facilities*.

[Ref. Department of Water Affairs and Forestry: *Minimum Requirements for Monitoring at Waste Management Facilities*, Pretoria, 1998.]

4.7.3 Preliminary Environmental Impact Assessment

The Preliminary Environmental Impact Assessment is considered to represent a preliminary phase of the full EIA described in Section 7 and is therefore to be carried out in accordance with the principles described in Section 7. While this is not a full EIA, it must re-address all the environmental siting criteria relating to the site which were considered during the candidate landfill site identification and ranking exercises.

Critical factors must be identified in the Preliminary EIA and must be discussed and addressed in the Feasibility Report. This assessment, based on the level of investigation conducted, must confirm that the identified critical factors can be addressed and that there are no Fatal Flaws.

4.7.4 Conceptual design and consideration of critical factors

The Feasibility Report must address any critical factors identified by discussing proposed solutions in the context of the envisaged conceptual design. In other instances, critical factors might be addressed by means of special operating procedures.

4.7.5 Maps and plans

The Feasibility Report must be illustrated with maps and plans. As a Minimum Requirement, the 1:50 000 topographical map and 1:10 000 orthophoto map, where available, must be included. Between them, both maps must indicate the position of the disposal site and must show the surrounding area to a distance of one kilometre, showing the 1 in 50 year flood line, position of boreholes, wells, springs, dams and water courses, archaeological, palaeontological, cultural and historical sites, important roads and transportation corridors, surrounding land uses and waste generation area served. Existing and proposed land use and development must also be indicated.

Should any other relevant maps or plans be readily available at this stage of the investigation, these could be included.

4.7.6 Further consultation with Interested and Affected Parties

It is a Minimum Requirement that at this stage,

further attempts be made to notify and register IAPs who could be affected by the top candidate landfill. Even if a candidate landfill is found to be technically feasible, it is not feasible unless it is acceptable to the majority of the IAPs. Acceptance by the IAPs immediately affected by the project therefore represents a critical factor in determining the feasibility of the proposed candidate landfill site. Justified public resistance to a site may be regarded as a Fatal Flaw by the Department and DEAT (Province). These departments may, however, also overrule unjustified public resistance.

It is therefore a Minimum Requirement that those IAPs who would be immediately affected by the site under consideration be included in the consultative process. The IAPs must be identified and fully informed of the proposed development and its potential implications, so that their input can be obtained. The objective of this would be to ensure that the IAPs concerns are addressed in a responsible manner. If the acceptance of the IAPs can be obtained, the feasibility of a given candidate landfill site can be confirmed.

It is also essential that the local authority in whose area the site is located be fully involved in the consultative process. This is because, in terms of Section 39 of the Health Act 1977, the local authority is responsible for determining the zoning and/or the consent land-use associated with the proposed site. In doing this, the local authority is also responsible for controlling any future development within a buffer zone surrounding a site (see Appendix 4.3).

The consultative process must be fully documented in the Feasibility Report. A Record of Decision issued by the DEAT (Province) must also be included, confirming that the site is acceptable to the IAPs for the intended purpose.

Once the Feasibility Report has been completed, it is a Minimum Requirement that it be submitted and, where practicable, presented to the Department and the IAPs. While the Department officially receives copies of the report, it must also be made freely available to the IAPs.

The Department will co-ordinate and liaise with all other relevant local, provincial and state departments to obtain confirmation of site feasibility. Where there is any doubt regarding adequate consensus, the Department may also liaise with the IAPs.

If the Department finds the site feasible, this will be communicated to the applicant in writing. This communication could include specific directives from the respective departments.

Once written acceptance of feasibility has been obtained from the Department, the site selection process is complete. The applicant can then begin the permitting procedure and the more detailed investigations of the site.

4.7.7 Consideration of unpermitted operating landfills

There are many operating landfills in South Africa which are not permitted in terms of the Environment Conservation Act (Section 20), (see Section 5.1). These range from well run operations which have not yet been permitted to situations where uncontrolled dumping of waste has occurred

on a large scale. Examples of the latter would include ‘borrow pits’ which are situated adjacent to townships and which have been developed into substantial informal and uncontrolled landfills. All unpermitted landfills must be classified and assessed in consultation with the Department, to determine the environmental risk which they pose.

In certain cases, unpermitted landfills will pose little environmental risk. This may be because of sound siting, design and operation, or simply because of the high ash and low putrescible content of the waste, or because significant leachate is not generated. Such sites could be upgraded in terms of design and operation, and permitted for continued operation in accordance with the Minimum Requirements.

Some unpermitted landfills may pose a risk to the environment because of a high pollution potential. If these cannot be upgraded to comply with the relevant objectives of the Minimum Requirements and environmental legislation, they must be closed in accordance with the Minimum Requirements and relevant environmental legislation. This usually requires site rehabilitation and the development of a replacement facility.

Where unpermitted operating landfills are to be upgraded or to continue operation until closure, it is a Minimum Requirement that the IAPs be involved in the decision making. This is also required in terms of the EIARs.

TABLE 4
Minimum Requirements for Site Selection

LEGEND B⁻ = No significant leachate produced B⁺ = Significant leachate produced R = Requirement N = Not a requirement F = Flag: special consideration to be given by expert or Departmental representative	CLASSIFICATION SYSTEM									
	G General Waste								H Hazardous Waste	
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		H:h Hazard Rating 3 & 4	H:H Hazard Rating 1-4
MINIMUM REQUIREMENTS	B⁻	B⁺	B⁻	B⁺	B⁻	B⁺	B⁻	B⁺		
Consult <i>Figure 6</i> and apply as appropriate	R	R	R	R	R	R	R	R	R	R
Classify proposed site	R	R	R	R	R	R	R	R	R	R
Notify IAPs of the necessity and intention to develop a landfill	R	R	R	R	R	R	R	R	R	R
Liaise with IAPs	R	R	R	R	R	R	R	R	R	R
Eliminate areas with fatal flaws	R	R	R	R	R	R	R	R	R	R
Identify candidate landfill sites	R	R	R	R	R	R	R	R	R	R
Buffer zone (m)	200	200	400	400	F	F	F	F	F	F
Minimum unsaturated zone	2m	2m	2m	F	F	F	F	F	F	F
Rank sites as indicated	F	F	R	R	R	R	R	R	R	R
Present ranked sites to IAPs	F	F	R	R	R	R	R	R	R	R
Site Feasibility Study	F	F	R	R	R	R	R	R	R	R
Site description	R	R	R	R	R	R	R	R	R	R
Complete Permit Application Form	R	R	R	R	R	R	R	R	R	R

LEGEND	CLASSIFICATION SYSTEM									
	G								H	
	General Waste								Hazardous Waste	
MINIMUM REQUIREMENTS	C		S		M		L		H:h	H:H
	Communal Landfill		Small Landfill		Medium Landfill		Large Landfill		Hazard Rating 3 & 4	Hazard Rating 1-4
	B ⁻	B ⁺	B ⁻	B ⁺	B ⁻	B ⁺	B ⁻	B ⁺		
Preliminary Geohydrological Investigation	N	F	R	R	R	R	R	R	R	R
Preliminary Environmental Impact Assessment	F	F	R	R	R	R	R	R	R	R
Identify critical factors	R	R	R	R	R	R	R	R	R	R
Assess critical factors	R	R	R	R	R	R	R	R	R	R
Confirm no fatal flaws	R	R	R	R	R	R	R	R	R	R
Confirm best site with IAPs and present results in Ranking Report	F	F	R	R	R	R	R	R	R	R
Compile Feasibility Report and present to Department, DEAT (Province) & IAPs	F	F	R	R	R	R	R	R	R	R
Departments' confirmation of feasibility	F	F	R	R	R	R	R	R	R	R