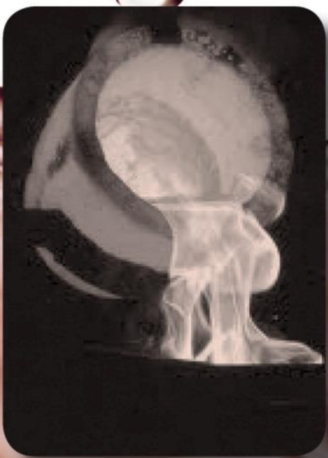
Water Resource Planning Systems Series

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



Assessment of the Water Quantity and Quality of the Witwatersrand Mine Voids

Study Report No. 5.2

P RSA 000/00/16512/2

May 2013

EDITION 1

water affairs

Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF WATER AFFAIRS

Water Resource Planning Systems Series

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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**.

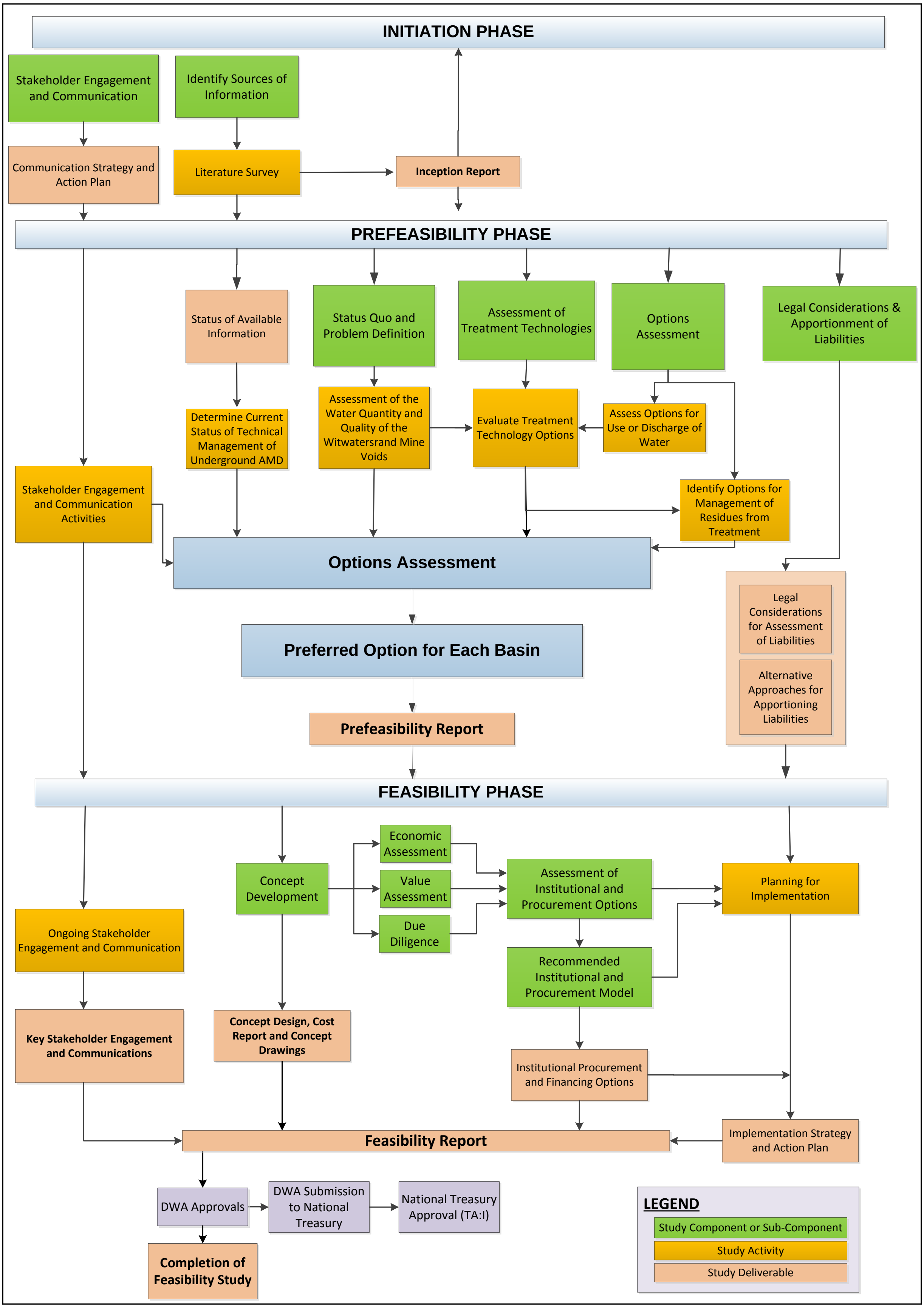

Figure 1: Study phases and components

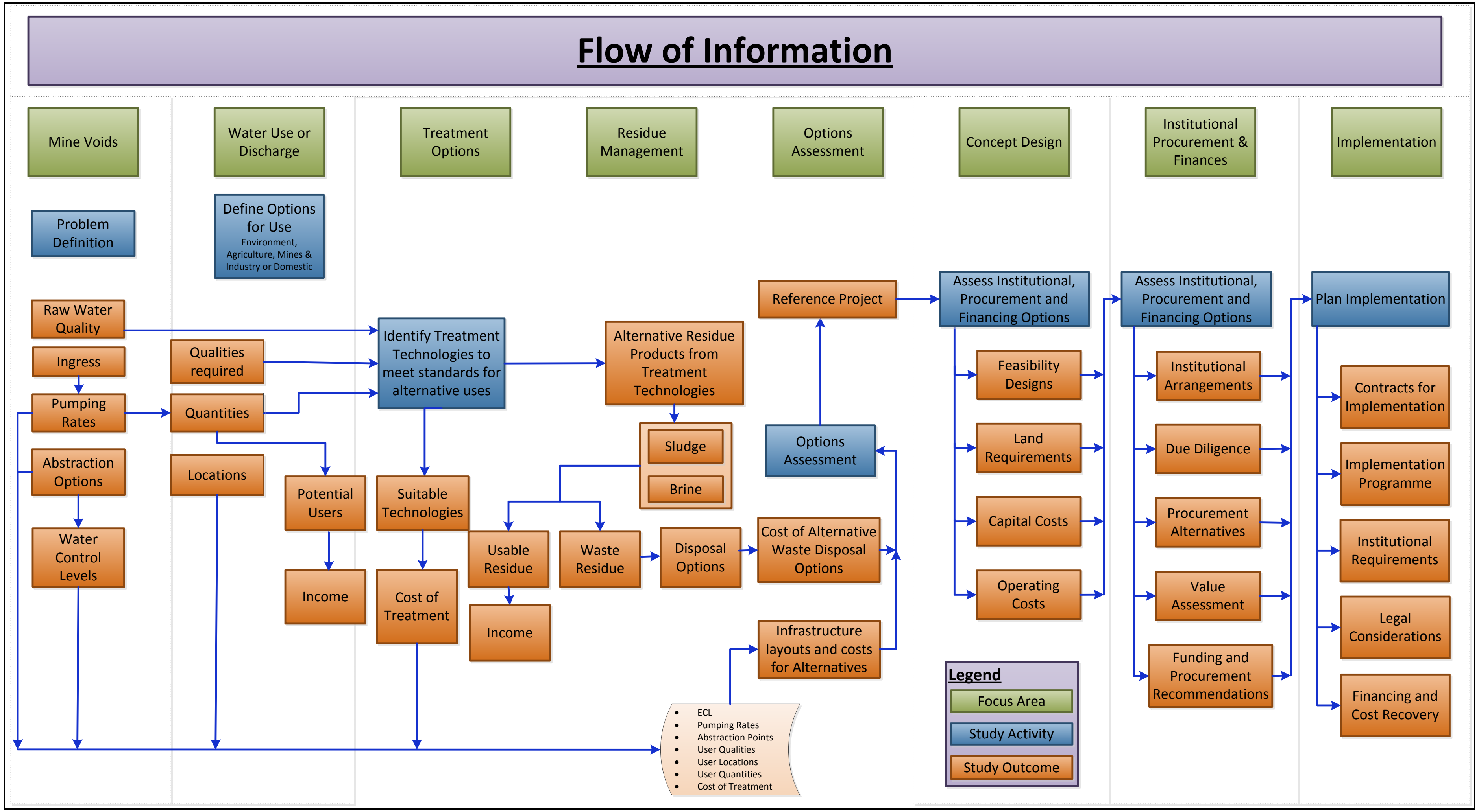

Figure 2: Flow of information throughout the Study

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 "xxxvi" and "xl" respectively.

APPROVAL

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David Sislen	World Bank
Marcus Wishart	World Bank

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

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

For this specific report, valuable inputs were also received from individuals (that were not members of the SMC or SSC) from external organisations, such as the City of Johannesburg Metropolitan Municipality, Gold Reef City and mines (Rand Uranium, Gold One and DRD/ERPM). These inputs are duly appreciated and acknowledged.

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

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

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The firms comprising the Professional Services Provider team for this study were:

Aurecon South Africa (Pty) Ltd;
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Shepstone & Wylie Attorneys; and
Various independent consultants, not mentioned separately.

EXECUTIVE SUMMARY

Active mining and dewatering of the gold mines along the West, Central and East Rand underground mining basins (hereinafter referred to as the "Western, Central and Eastern Basins" of the Witwatersrand) declined and essentially ceased in 2010. The void left as a result of mining has been steadily filling with water, which interacts with the exposed rocks in the mine void to form Acid Mine Drainage (AMD). In the case of the Western Basin, the AMD has been decanting on surface since 2002. Surface decanting in other basins is predicted to occur in the not too distant future if no action is taken. AMD is known to be of poor quality and poses a threat to the environment and to the water resources of the Vaal and Crocodile River basins.

Currently, Short-Term Interventions (STI) are underway that involve the installation of pumping facilities to stop uncontrolled surface decanting in the Western Basin and to prevent surface decanting from taking place in the other basins. Facilities for the basic treatment of the water are also to be installed. In parallel with these developments, a more permanent solution to the problem is being investigated.

This report provides an assessment of the geology, hydrogeology and hydrochemistry of the Western, Central and Eastern Basins to provide the background information necessary for controlling the rising AMD to protect the environment and socio-economic assets and for the planning of abstraction (location and pumping rates) and water treatment for the Long-Term Solution (LTS).

The report also assesses aspects of the STI and how these can either be influenced by the LTS or be effectively incorporated into the LTS. Although there are some aspects where an alternative LTS can be considered, the STI is considered acceptable to meet the requirements as stipulated in the directives that were issued by the Department of Water Affairs to the Trans-Caledon Tunnel Authority (TCTA).

The report compares the findings of this study and the results of the studies for the Short-Term Intervention (STI) with respect to critical water levels, abstraction points, ingress rates and water qualities.

In the Western and Eastern basins the programme for the STI is such that this study could influence the planning of the STI. However in the Central basin the programme for implementation of the STI meant that the location for abstraction and thus neutralisation was already fixed. Although this study has reached somewhat different conclusions on the critical water levels, water quality and required pumping rates the findings of the STI study are conservative and adjustments that will inevitably be required during operation can be accommodated. The abstraction points proposed by the STI and LTS for the Western and Central basins are the same. However in the Central basin the STI abstraction point at South West Vertical (SWV) Shaft may have some long-term risks and in the long-term the

use of one or more additional abstraction points may be beneficial or necessary in the longer term. The results of the study are summarised below:

Critical water levels

A key objective of this study component was to define critical water levels in each of the basins and estimate the time at which the water in each basin will reach these levels. The critical water levels under consideration are:

- *Environmental Critical Level (ECL),being the level above which the water in the mine voids at the critical location (that is where the environmental features to be protected are at the lowest elevations) should not be allowed to rise, to protect specific environmental features, including groundwater resources;*
- *Socio-Economic Critical Level (SECL), being 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; and*
- *Target Operating Level (TOL), the level in the mine void at each abstraction point, at which the water surface should generally be maintained by pumping, or gravity flow, and is determined by the freeboard required below the ECL or SECL across the basin.*

In the Western Basin where the mine void water is at or very close to surface at Black Reef Incline (BRI), the objective is to eliminate or reduce the risks of polluting the springs feeding the Tweelopies Spruit and of polluting the subsurface flow to the Zwartkrans Compartment dolomite aquifer that hosts the Cradle of Humankind. It is anticipated that this will be achieved if the mine void water is prevented from entering the dolomite aquifer via the Black Reef Mine workings at approximately 1 610 m amsl. Therefore an ECL of 1 600 m amsl is proposed. In the long-term it is anticipated that a freeboard (or "buffer") of 15 m should be adequate and an initial TOL of 1 585 m amsl is recommended. The water should be held at that level for an appropriate duration to allow the water level in the entire void to drain down to that level and establish whether the water quality downstream in the Tweelopies Spruit is free of pollution from AMD. If leakage or direct pollution by AMD ceases and if the ECL has not been breached with a TOL of 1 585 m amsl, it should be maintained (i.e. the water could be held at this level). If the situation is not satisfactory, the level should be lowered further until the desired result is obtained. It is expected that at an ECL of 1 565 m amsl, which should be below the base of the dolomite outlier, all pollution will have ceased. In this case the TOL is recommended to be at 1 550 m amsl, which is the same as the ECL proposed by the STI. No SECL is currently envisaged for the Western Basin.

For the Central Basin the ECL is based on a depth of 100 m below surface at the anticipated decant points of East Rand Proprietary Mines (ERPM), Cinderella East and Cinderella West at 1 620 m amsl to protect the shallow weathered aquifers and the ground water regime feeding springs and base flow in streams. A program of drilling and water quality testing in the ERPM area is recommended to improve definition of the depths of the shallow aquifer *and provide baseline water quality data, which will enable a more accurate elevation to be determined for the ECL.*

In the long-term a freeboard, or buffer, of 20 m is expected to be adequate to protect the ECL. The recommended TOL is thus 1 500 m amsl. However, due to the size of the basin (55 km across) there are a number of unknowns, including how the water levels in the mine void will vary, both spatially and temporally, so an initial freeboard (buffer) of 50 m is recommended, with a TOL of 1 470 m amsl, which corresponds with the ECL (including a "buffer") of 1 467 m amsl proposed by the STI. The freeboard and thus TOL should be adjusted in future, based on the monitoring of the water levels in the void across the basin. The current estimate for the water levels in the Crown Mines No. 14 Shaft to reach the ECL proposed by the Trans-Caledon Tunnel Authority (TCTA) (1 467 m amsl) is estimated at ca. January 2014, with surface decant sometime in 2015.

The Gold Reef City (GRC) museum tourist level (1 484 m amsl) in Crown Mines No. 14 (CM 14) Shaft was taken to be the critical factor in determining the SECL. The SECL is set at an elevation of 1 474 m amsl to accommodate the lowering of the double decker conveyance and to ensure that the museum can still be visited as a heritage site. If the SECL is used, then the TOL must ensure that there is sufficient freeboard to allow for potential slow flow rates between GRC and the pump site. A long-term TOL of 1 454 m amsl is proposed if the SECL is to be protected. Currently, GRC are investigating the possible relocation of the museum facility from 5 Level to 2 Level (1 624 m amsl).

An alternative SECL of 1 246 m amsl, about 400 m below surface at SWV Shaft is being considered to allow mining to that depth. If this takes place, then, before mining operations close down, the proposed ECL or the SECL for GRC and associated TOL will have to be set before the water is allowed to rise. Whatever levels are set, monitoring of the near surface aquifers of the basin is very important.

In the Eastern Basin an ECL of 1 470 m amsl, about 80 m below surface and thus the water table in the dolomitic aquifer, is expected to be low enough to protect the aquifer from pollution. A long-term freeboard of 20 m is proposed giving a TOL of 1 450 m amsl. However, it is recommended that initially, an ECL of 1 280 m amsl at the base of the dolomite be adopted. This ECL, 190 m lower than the proposed long-term ECL, is considered to be very conservative and no freeboard or buffer is proposed so the associated TOL is also 1 280 m amsl. This is also the ECL proposed by the STI, also set to be at the bottom of the dolomite.

If adequate monitoring of the water quality in the dolomite has been established, and no pollution is observed at the TOL/ECL of 1 280 m amsl, the water level can be allowed to rise, in say 10-metre steps every three months, possibly as high as 1 470 m amsl provided that the recommended monitoring is carried out and does not detect any pollution from AMD.

No SECL is currently set for the Eastern Basin.

The ECL in the Eastern Basin (1 280 m amsl) is estimated in this study to be reached by middle 2014. The TCTA (2013, presentation to SSC on 16 May 2013) predicts that the ECL will be reached in August 2014, and these slight differences may be due to extrapolation issues with limited data.

In all three basins there remains potential for new mining operations to become economically feasible, especially with increasing gold prices, in which case appropriate SECLs would have to be set.

Surface water ingress

The impact of surface water ingress directly into the underground workings is significant for all three basins. The ingress mainly occurs via reef outcrops, opencast mine pits and backfilled workings, tailings dams, as well as from rivers and other water bodies. The bulk of the ingress cannot easily be controlled as there are many diffuse sources within the basins. Follow up studies should therefore be carried out to establish both the practicality and cost effectiveness of controlling ingress from various sources. In the long-term this could potentially reduce the required pumping rates and hence lower pumping, treatment and maintenance costs.

It is predicted that climate change will cause an increase in average rainfall and hence must be taken into account in future studies regarding ingress volume predictions. The impact of climate change could be fairly significant in the Western and Eastern basins mainly due to the extensive river systems within these basins. A smaller impact is expected in the Central Basin as the bulk of ingress occurs from high base flows in rivers due to leaking sewer lines and drainage systems.

Pumping rates

In this study, pumping rates required to maintain a static water level at a particular elevation in support of SECLs or ECLs were calculated using void volume and historic water level data, and are presented in comparison with those of the TCTA (2011) in ***Table 1****.*

Table 1: Comparison of pumping rates to maintain critical water levels.

Basin	Approximate Average Pumping Rate (TCTA) (Mℓ/d)		Proposed Pump Capacity and Average Rate (this study) (Mℓ/d)	
	Average	Range	Pump Capacity	Average Rate
Western	27	23 - 35	40	23
Central	57	34 - 84	50	46
Eastern	82	38 - 110	100	80

Shaft Selection

The success of the pumping installation depends on its ability to lower the void water level ensuring that decant and pollution of groundwater does not occur. A desk top review into shaft selection was undertaken which involved review of mine plans and personal interviews where required.

It is considered preferable to pump from shafts that are well connected with the mine void at shallow levels to maximise the recycling of shallow ingress, leaving the deep, highly contaminated water undisturbed. Turnover of the shallow ingress water will lead to more rapid flushing of the shallow system. Pumping from a shaft that is connected to the mine void close to surface on multiple levels also ensures connectivity even if there is a collapse on one level.

For the Western Basin, Rand Uranium No. 8 Shaft (also referred to as No. 8 Shaft) suits all the criteria stipulated above and is currently used to pump AMD water using two submersible pumps with a capacity of 8 Mℓ/d each. The connectivity of No. 8 Shaft with the mine void has been proven, but its stability is a concern and the STI is considering using No. 9 Shaft.

For the Central Basin, the SWV Shaft at ERPM was identified in the TCTA (2011) Study as the site where the pumps will be installed. A possible disadvantage of this shaft is that its shallowest connection with the ERPM mine void is at 24 Level, 1 080 mbs (metres below surface). The AMD from all the other compartments will decant from West to East through connections at relatively shallow depths. All the water will decant into the ERPM compartment at about 575 mbs. Thus, due to compartmentalisation of the Central Basin, it is likely that only relatively shallow water will be drawn towards ERPM from the west and the deep mine water in the west and central parts of the basin will remain undisturbed. The haulage at 24 Level will have to carry the entire void discharge and a collapse could restrict the flow. Water would then be drawn up the SWV Sub-shaft, which is connected to the void at the much deeper 30 Level and below. Water will then be drawn from considerable depth if this occurs. However, this Study considers the SWV Shaft to be suitable for at least the medium term (10 – 15 years).

It was believed that drawing water from great depths would prolong flushing of the void. There is a ventilation shaft close to SWV Shaft (500 m north-west of SWV) which could serve as back-up pumping location in the event of problems with SWV and could be connected directly to the HDS plant relatively easily. This shaft was considered in the STI investigations but was rejected because it was too small (it has a 6 m diameter) and was connected to the void by a single tunnel. It is recommended that this ventilation shaft be located and protected for possible use in the future.

In a long-term solution, other pumping strategies should be investigated in the Central Basin which could involve multiple extraction points which have greater connectivity with the void at a shallow level.

A preferable long-term approach would be to abstract at SWV and up to four other locations. Most of the vertical shafts still accessible today on the Central Rand intersect the void at considerable depth. The reason is that most of the shallower reefs were accessed by incline shafts, such as Cason Shaft (discussed in Section 7.6.2).

The incline shafts have the advantage that they are connected directly to the mine void at shallower depths, on multiple levels, and even without headgear can be easily accessed. However, preparing and equipping an incline shaft would require considerable lead times and may not be practical for large submersible pumps. The upper portions of these shafts are located on the reef layer and as a result are not regular but may roll with the reef. There is also some risk regarding shaft stability, when considering incline shafts over vertical shafts. A detailed investigation of potential vertical and incline shafts that may have greater interconnectivity would require a detailed study of multiple criteria and is beyond the scope of this study. This should be undertaken as soon as possible so that there is an alternative plan if problems are encountered.

Access and infrastructural constraints may necessitate the consideration of an alternative strategy of large-diameter boreholes drilled into the mine void for pump installation. The holes should be drilled to intersect carefully selected locations in the mine void, with good connectivity at shallow and other depths. This alternative strategy will reduce the risk from failure of a pump shaft due to collapse of the shaft itself or underground tunnels. In addition, pumping from shallower levels is likely to result in a more rapid improvement in the pumped water quality. Pipelines may have to be installed to convey water to central treatment plants in a similar manner to that employed by the companies that re-treat slimes dams. The use of multiple shaft and borehole pump sites will be further investigated in the options analysis of this Feasibility Study.

In the Eastern Basin, Grootvlei No. 3 Shaft has been identified by the TCTA as a possible pumping shaft, as it has been utilised in the past and proved to be sufficiently connected to the void. Examination of the mine plans confirmed that it is well connected to the Kimberly reef and, because of a plug in the shaft above the connection to the deeper Nigel reef, only indirectly connected to that reef. Water pumped from the shaft cannot be drawn directly from the Nigel reef and will mainly be water from the shallower Kimberly reef. However, due to its proximity to the dolomites in the area, lack of space for the required infrastructure, the fact that the ground level at the shaft is below the 1:100 floodline and in order to reduce the pumping head, suitable alternatives were sought and several considered. Based on an inventory of shafts in the Eastern Basin prepared by Gold One and camera surveys carried out by Mine Rescue Services, Marievale No. 5 Shaft was identified as being the most suitable alternative. This shaft is located south of the dolomite and wetlands, avoiding the return of water releases to the void. It has direct connectivity, via haulages, to both the Nigel (Main) Reef and Kimberley Reef. There is also adequate space for pumping infrastructure.

On balance, due to the fact that Grootvlei No. 3 Shaft draws directly from the shallower Kimberley Reef void and only indirectly from the deeper Nigel Reef void (due to the plug), *and that successful pumping was carried out at Grootvlei No. 3 Shaft in the past this shaft is considered marginally superior to Marievale No. 5 Shaft for the abstraction, provided the surface concerns can be managed. However, Marievale No. 5 Shaft could be a suitable alternative should the need arise.*

In the Central Basin and possibly in the Eastern Basin it is recommended that pumping be undertaken from more than one shaft per basin. Ideally, shafts that are better connected to the mine void at multiple and preferably shallow levels are recommended. Pumping from several shafts will reduce the danger of a shaft becoming ineffective due to collapse of either the shaft itself or of underground haulages. In addition, pumping from shallower levels is likely to result in a more rapid improvement in water quality, at least in the Central Basin where direct surface water ingress is evident.

Water quality

*In **Table 2**, the current estimations of AMD chemistry (including surface ingress, shaft water, etc.) in the three basins are compared with those given by the TCTA (2011). As a general observation, it appears that the data sources consulted in this study report lower salt concentrations than those recorded by the TCTA (2011). At least some of this is due to dilution effects from surface water ingress, as illustrated in **Figure 1**.*

*The data cluster marked K in **Figure 1** is regarded as the best estimate of primary AMD. These samples have pH values of between 2 and 4, and TDS values of ca. 3 850 ± 1 000 mg/ℓ. The combination of salts shows relatively little variation in composition. The weight ratios of SO_4:Ca:Mg:Na:Fe:Al = 65:15:5:5:1:0.5 (ranges: 60-75:10-25:4-7:4-10:0.1-6:0-3), as determined for Central Basin data, on average seem to hold well for the other basins as well.*

Most of the Western Basin AMD samples plot in a narrow band at an electrical conductivity (EC) of ca. 350 mS/m, which represents about 3 850 mg/ℓ of total dissolved solids (TDS), and recorded pH values of between 2 and 7, depending on the degree of neutralisation (red arrow in Figure 1), probably by interaction with dolomitic water.

The Central Basin data is scattered over a wide field, reflecting the diversity of samples in the database, ranging from extremely contaminated surface samples (EC ~1 050 mS/m) to water in the potable range. A large number of samples plot at EC ~100 to 200 mS/m and pH between 2 and 6. The latter samples originate largely from the Durban Roodepoort Deep (DRD) Circular and CM 3 Vent shafts, and represent the dilution effect of surface ingress (blue arrow) on the AMD in the mine void.

The Eastern Basin samples cluster at an EC of about 300 mS/m (TDS ~3 300 mg/ℓ) and pH between 5 and 8. These samples follow a trend (black arrow) which summarises the recorded improvement of the water quality during pumping. This improvement is probably the combined result of dilution and neutralisation by dolomite-equilibrated water.

*As a reasonable approximation of the likely water qualities during abstraction, **Table 3** presents water chemistry data from underground samples only (or direct decant sites in the case of the Western Basin).*

It must be emphasised that the database which was available at the time of finalising this report was inadequate. However, prior to the actual design of the long-term treatment facilities, high quality data will become available from the monitoring associated with the Short-Term Intervention which can be used to refine the designs.

Table 2: Summary comparison of chemical data

Water Quality Parameter	Units	TCTA Report			This Report		
		Basin			Basin		
		Western	Central	Eastern	Western	Central	Eastern
		(95th percentile)	(95th percentile)	(flooded condition)+	(95th percentile)	(95th percentile)	(95th percentile)
pH*	-	3.4-4.0#	2.3	5#	3	3.2	7.1
TDS	mg/ℓ	7 174	7 700	5 500	5 400^	3 700^	4 300^
Conductivity	mS/m	548	730	450	426	354	367
Calcium (Ca)	mg/ℓ	461	580	550	823	483	421
Magnesium (Mg)	mg/ℓ	345	380	230	-	161	165
Sodium (Na)	mg/ℓ	139	150	325	243	185	264
Sulphate (SO_4)	mg/ℓ	4 556	5 200	3 275	3 410	2 464	2 581
Chloride (Cl)	mg/ℓ	65	260	260	-	69	253
Acidity/Alkalinity	mg/ℓ	2 560**	2 425**	750**	1 255+	125##	541##
Iron (Fe)	mg/ℓ	933	1 000	370	799	177	206
Aluminium (Al)	mg/ℓ	54	50	1	-	44	2
Manganese (Mn)	mg/ℓ	312	60	10	114	20	6
Uranium (U)	mg/ℓ	0.2	-	-	0.1	0.2	0.5

*5th percentile # Assumed 5th percentiles **Acidity - Calculated $CaCO_3$ +Acidity mg/l ##Alkalinity mg/l $CaCO_3$
^Estimated and numbers rounded up All units as quoted in source documents
+Mine water quality in the Eastern Basin is of a relatively good quality for a number of geohydrological reasons, such as recharge of the mine workings with relatively good quality dolomitic water. However, as the basin is flooded, and due to associated mobilisation of accumulated pyrite oxidation products, the water quality will deteriorate in time if not addressed (TCTA Due Diligence Report 2011).

Table 3: Summary of 95th percentile underground/decant mine water chemistry

Parameter	Unit	Basin 95th Percentile		
		Western	Central	Eastern
pH#	@ 25°C	3.5	2.4	5.9
TDS^	mg/ℓ	5 434	4 592	3 358
Conductivity	mS/m @ 25°C	442	465	363
Ca	mg/ℓ	703	563	421
Mg	mg/ℓ	-	258	166
Na	mg/ℓ	227	171	264
SO_4	mg/ℓ	3 623	3 062	2 289
Cl	mg/ℓ	-	146	254
Acidity/Alkalinity	mg/ℓ	1 520	-	560
Fe	mg/ℓ	954	108	227
Al	mg/ℓ	-	193	2.4
Mn	mg/ℓ	89	50	5.9

^Estimated # 5th percentile

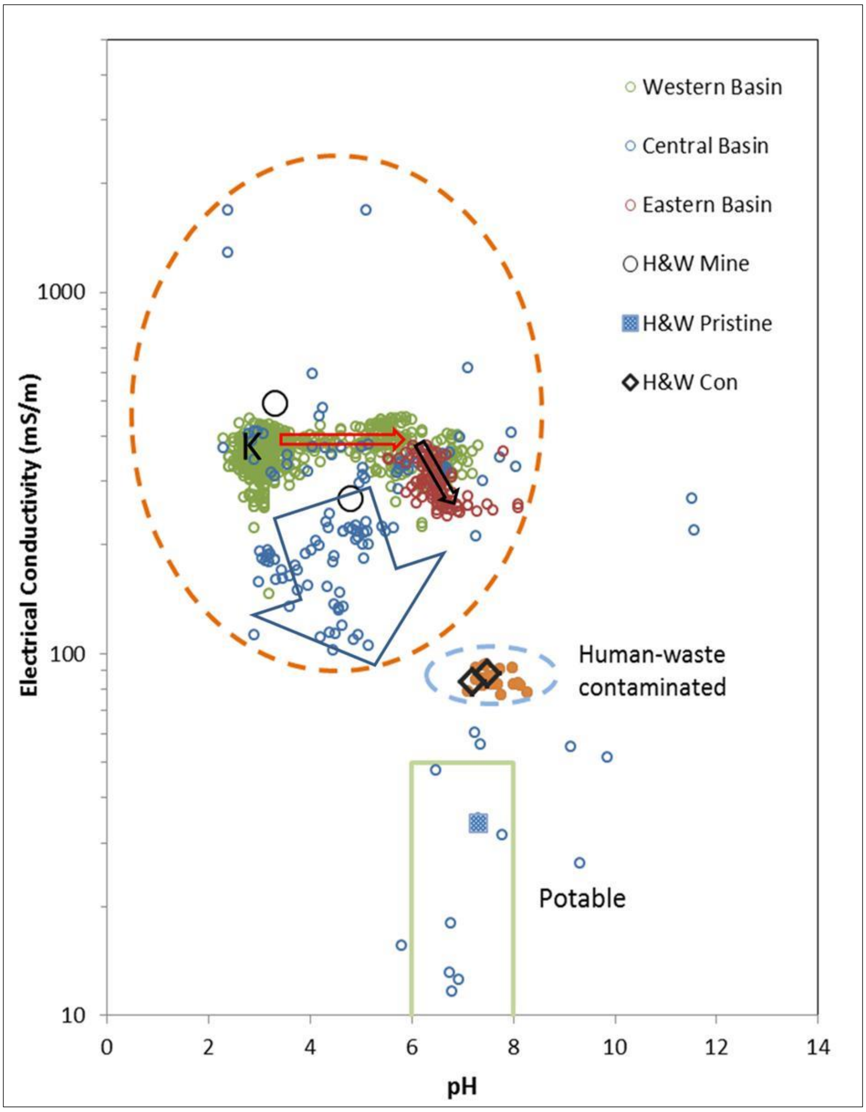

Figure 1: Simplified chemical relationships (H&W = Holland and Witthüser, 2009)

The uncertainties inherent in the data, and in particular in the detail of the void characteristics, do not allow for high accuracy predictions to be made. These uncertainties will best be solved by adopting an initially conservative approach and by a well-considered water quality monitoring program once pumping commences as part of the STI. However, some variability in the water quality during the initial stages of pumping should be expected. This situation will stabilise when the systems approach dynamic equilibrium.

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Appendices

LIST OF ACRONYMS

ABC	Alkali-Barium-Calcium
AKTEX	Deeds Office Deeds Summary
AMD	Acid Mine Drainage
AME	Africa Middle East
ARD	Acid Rock Drainage
ARL	Acid Rain Leach
ARLP	Acid Rain Leach Procedure
BBBEE	Broad Based Black Economic Empowerment
BEE	Black Economic Empowerment
BID	Background Information Document
BKS	BKS Group (Pty) Ltd
BRI	Black Reef Incline
CAPEX	Capital Expenditure
CB	Central Basin
CBA	Cost Benefit Analysis
CBD	Central Business District
CD	City Deep
CBEC	Central Basin Environmental Corporation
CGS	Council for Geoscience
CM	Crown Mines
CMR	Consolidated Marin Reef
CRG	Central Rand Gold
CPlan	Conservation Plan
CSIR	Council for Scientific and Industrial Research
DAF	Dissolved Air Flotation
DBOM	Design, Build, Operate and Maintain
DBOMF	Design, Build, Operate, Maintain and Finance
DEM	Accurate Digital Elevation Models
DG	Director-General
DMR	Department of Mineral Resources
DO	Dissolved Oxygen
DRD	Durban Roodepoort Deep
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EB	Eastern Basin
EBEC	Eastern Basin Environmental Corporation
EC	Conductivity in millisiemen/metre
ECL	Environmental Critical Level
EI	Ecological Importance
EIA	Environmental Impact Assessment
EI&S	Ecological Importance and Sensitivity
EMP	Environmental Management Plan
ERPM	East Rand Proprietary Mines
FAQ	Frequently Asked Question
FBR	Fluid Bed Reactor
FM	Facilities Management

GAC	Granular Activated Carbon
GARD	Global Acid Rock Drainage
GCL	Geo-synthetic Clay Liner
GDARD	Gauteng Department of Agricultural and Rural Development
GIS	Geographic Information System
GLB+ Site	Large General Waste Disposal Site
GRC	Gold Reef City Museum
GRCTF	Gold Reef City Tourist Facility
HDI	Historically Disadvantaged Individual
HDPE	High Density Polyethylene
HDS	High Density Sludge
H:H Site	Hazardous Waste Disposal Site
HP	High Pressure
IGTT	Intra-Governmental Task Team
IMC	Inter-Ministerial Committee
IX	Ion Exchange
LTS	Long-Term Solution
MA	Management Authority
m amsl	meters above mean sea level
MAP	Mean Annual Precipitation
ND	Nominal Diameter
NEMA (107:1998)	National Environment Management Act, 1998 (Act No. 107 of 1998)
NEMWA (59:2008)	National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008)
NGO	Non-Governmental Organisation
NNR	National Nuclear Regulator
NP	Nitrogen and Phosphorous
NPV	Net Present Value
NRV	Non-Return Valve
NWA (36:1998)	National Water Act, 1998 (Act No. 36 of 1998)
NWAss	National Water Association
NWRS	National Water Resources Strategy
O&M	Operation and Maintenance
OPEX	Operating Expenditure
PEC	Project Executive Committee
PES	Present Ecological State
PFMA (1:1999)	Public Finance Management Act, 1999 (Act No. 1 of 1999)
PPP	Public Private Partnership
P Pub P	Public-Public Partnership
PSC	Public Sector Comparator
PSCM	Public Sector Comparator Model
PSP	Professional Service Provider
P2W	Pollution to Water
RDM	Resource Directed Measures
REGM	Randfontein Estates Gold Mine
RfI	Request for Information
RfQ	Request for Qualifications
RfP	Request for Proposals
RL	Rand Leases
RO	Reverse Osmosis
RoD	Robinson Deep

RsD	Rose Deep
RQO	Resource Quality Objective
RWQO	Resource Water Quality Objective
SAC	Study Administration Committee
SAHRA	South African Heritage Resources Agency
SANS	South African National Standards
SAR	Sodium Adsorption Ratio
SECL	Socio-Economic Critical Level
SJ	Simmer and Jack
SMC	Study Management Committee
SMME	Small, Medium, Micro Enterprises
SOE	State Owned Entity
SoW	Scope of Work
SRB	Sulphate Reducing Bacteria
SRK	SRK Consulting (Pty) Ltd
SSC	Study Stakeholder Committee
STI	Short-Term Intervention
STS	Short-Term Solution
SWB	Soil Water Balance
SWV	South West Vertical
TA 1	Treasury Approval 1
TCTA	Trans-Caledon Tunnel Authority
TOL	Target Operating Level
ToR	Terms of Reference
TRU	Thermal Recovery Unit
T&T	Turner & Townsend
TSF	Tailings Storage Facility
UNEP	United Nations Environmental Programme
VCR	Ventersdorp Contact Reef
VRESAP	Vaal River Eastern Sub-system Augmentation Project
WB	Western Basin
WBEC	Western Basin Environmental Corporation
WC&WDM	Water Conservation & Water Demand Management
WDC	Waste Discharge Charge
WDCS	Waste Discharge Charge System
WESSA	Wildlife and Environment Society of South Africa
WMA	Water Management Area
WQ	Water Quality
WRC	Water Research Commission
WUC	Western Utilities Corporation
WWTW	Waste Water Treatment Works

LIST OF CHEMICAL CONSTITUENTS

Al	Aluminium
Alk	Alkalinity
$BaCO_3$	Barium Carbonate
$BaSO_4$	Barite
Ca	Calcium
Ca^{2+}	Ionic Calcium Solution

$CaCO_2$	Alkalinity
$CaCO_3$	Calcium Carbonate
$CaSO_4$	Gypsum
Cl	Chloride
COD	Chemical Oxygen Demand
F	Fluoride
Fe	Iron
K	Potassium
Mg	Magnesium
Mg^{2+}	Ionic Magnesium Solution
$Mg(CH)_2$	Magnesium Hydroxide
Mℓ	Megalitre
Mn	Manganese
Na	Sodium
NH_4	Ammonia
NO_3	Nitrate
O_2	Dissolved Oxygen
PO_4	Phosphate
SiO_2	Silicon Dioxide
SO_4	Sulphate
TDS	Total Dissolved Solids
TH	Total Hardness
U	Uranium

UNITS OF MEASUREMENT

~	approximately
µg	microgram
µS	microsiemens
C	Celsius
cm	centimetre
d	day
ha	hectare
hr	hour
kℓ	kilolitre
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

Adit	**An adit is an entrance to an underground mine which is horizontal or nearly horizontal, by which the mine can be entered, drained of water, and ventilated.**
AMD	Acid mine drainage is formed when sulphide minerals in the geological strata, are exposed through mining activities and interact with oxygen and water to form a dilute solution of sulphuric acid and iron that leaches other metals from the material in which it forms. Acid mine drainage in the Witwatersrand typically has a pH value around 3 and is enriched in sulphate, iron and a number of metals, often including uranium.
Annexure	Documents produced by others attached to the report.
Appendix	Documents produced by the Feasibility Study attached to the report.
Aquifer	Zone below the surface capable of holding groundwater.
Central Basin	Central Rand underground mining basin.
Decant (surface)	Spontaneous surface discharge of water from underground mine workings.
Decant (subsurface)	Subsurface flow of water from one mine compartment or geological structure to another, typically occurring when underground mine voids fill and cascade consecutively from one underground compartment to another adjacent connected compartment.
Discharge (groundwater)	Seepage of groundwater at the surface.
Dyke	Vertical, planar body of igneous rock formed by the solidification of molten rock in a crack.
Eastern Basin	East Rand underground mining basin.
Environmental Critical Level	The level above which the water in the mine voids at the critical locations (that is where the environmental features to be protected are at the lowest elevations) should not be allowed to rise, to protect specific environmental features, including groundwater resources.
Fault	Crack in the earth along which differential movement of the rock mass has occurred.
Feasibility Study	An analysis and evaluation of a proposed project to determine if it is technically sound, socially acceptable, and economically and environmentally sustainable.
Freeboard	The vertical distance below the Socio Economic or Environmental Critical Level at the abstraction point, below which the water level should generally be maintained, to allow for hydraulic gradient across the basin, seasonal peak ingress, pump down time, and the like, i.e. to provide sufficient buffer capacity.
Groundwater	Water occupying openings below surface
Key stakeholder	Defined as directly affected parties, those who have a high level of negative or positive influence (in government and civil society domains, and on the direction and success of AMD long-term initiatives) and those whose input is critical to the study (for e.g.,

	representatives of various National, Provincial, and Local Government, NGOs, organised business, mining, industry, labour, agriculture, affected mines, affected water utilities, community leaders, academics, etc.).
Layout	The arrangement or configuration (site layout, pipe route, etc.) of a specific option.
Long-Term Solution	A solution that is sustainable in the long term with regards to the technical, ecological, legal, economic, financial and institutional aspects.
Mine plan	Accurate drawing showing the positions of mine excavations.
Option	One of a number of combinations of abstraction works, treatment processes, and solutions for the disposal of waste and utilisation of treated water.
Preferred option	The solution, or combination of solutions, for the three basins respectively and collectively, that will be selected for further investigation in the feasibility phase, and if found feasible, that would eventually be recommended for implementation.
Ramsar Convention	The Convention on Wetlands of International Importance, especially as Waterfowl Habitat - An international treaty for the conservation and sustainable utilization of wetlands, i.e., to stem the progressive encroachment on and loss of wetlands now and in the future, recognizing the fundamental ecological functions of wetlands and their economic, cultural, scientific, and recreational value. It is named after the town of Ramsar in Iran.
Reserve	The quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.
Resource Quality Objectives	Resource Quality Objectives (RQOs) capture the Management Class of the Classification System and the ecological needs determined in the Reserve into measurable management goals that give direction to resource managers as to how the resource needs to be managed. RQOs may relate to, the Reserve, the instream flow, the water level, the presence and concentration of particular substances in the water, the characteristics and quality of the water resource and the instream and riparian habitat, the characteristics and distribution of aquatic biota, the regulation or prohibition of instream or land-based activities which may affect the quantity of water in, or quality of the water resource; and any other characteristic, of the water resource in question.
Resource Water Quality Objectives	Is a numeric or descriptive instream (or in-aquifer) water quality objective, typically set at a finer resolution (spatial or temporal) than Resource Quality Objectives to provide greater detail upon which to base the management of water quality. (Resource Directed Management of Water Quality, 2007).
Request for Qualifications	A Request for Qualifications (RFQ) from Service Providers to allow a shortlist to be prepared. It is normally the first step in the procurement process.
Scenarios	An alternative projection of the macro environment which affects AMD, such as climate change, electricity load shedding, and changes in quality or quantity of water ingress to the mine void.
Service Provider	The generic term for the Special Purposes Vehicle (SPU) or contracting consortium that will design, build, operate and maintain and possibly finance the works.

Short-Term Interventions (Short-Term Solution as stated in Terms of Reference)	Emergency measures that are being implemented by the TCTA in the short-term in all three the basins while the long-term Feasibility Study is undertaken to protect the ECL, to neutralise the AMD and to remove metals from the AMD.
Socio-Economic Critical Level	The level above which the water at the critical location in the mine void must not be allowed to rise, to protect specific social or economic features, such as the Gold Reef City museum and active or planned mining.
Target Operating Level	The level in the mine void at each abstraction point, at which the water level should generally be maintained by pumping or gravity flow to allow for hydraulic gradient across the underground mining basin, seasonal peak ingress, pump down time, and the like, i.e. to provide sufficient buffer capacity or freeboard required below the ECL or SECL across the basin.
Water table	The level in an aquifer below which the said aquifer are filled with water.
Western Basin	West Rand underground mining basin.

1 INTRODUCTION

1.1 Aims and Objectives of this Component

The principal aim of this component of the study is to assess the present and likely future quantity and quality of the mine void water that is to be treated. In order to achieve this aim, a sound understanding of the following aspects is required:

- The geology and hydrogeology of the region;
- The spatial distribution and interconnectivity of the mine void that hosts the underground water;
- Sources of water ingress into the mine void; and
- Water qualities within the mine void and the variation therein.

A substantial number of previous studies have been completed on this subject and this report does not aim to provide a detailed review of each of these studies. However, the assessment is based on the wealth of information available as a result of previous work.

The main objectives of this component of the Feasibility Study are:

- To estimate the time at which the water in each basin will reach certain critical levels and when and where surface decant is expected to occur if the natural rate of rise continues unchecked. The critical levels under consideration are:
    - Environmental Critical Level (ECL), being the level which shall ensure the safety of the environment, including groundwater resources;
    - Socio-Economic Critical Level (SECL), being the level which shall preserve cultural-historic infrastructure and current or planned economic activity, e.g. mining;
    - Target Operating Level (TOL), being the optimum safe water level, below the ECL and SECL, which shall prevent, allowing for periodic fluctuation and maintenance, the ECL or ECL to be reached. The TOL will be based on engineering considerations and will be determined at a later stage in the study;
- To estimate the volumes of water that must be abstracted from various underground mining compartments to achieve and maintain agreed water levels and any changes with time;
- To assess the quality of the water delivered and which will need to be treated, as well as the probable changes with time;
- To provide confidence levels for all predictions. All the data presented in this report is based on the latest available information and the confidence levels are considered to be the best that the data allows; and
- To provide recommendations for further investigation by other components in the Feasibility Study, in particular the options analysis.

The potential water resource available in the mine void is often discussed but rarely quantified. **Table 1.1** provides estimates of the relative capacities of the Vaal Dam and the mine voids of the Western, Central and Eastern basins. The total combined capacity of the mine void is equivalent to about one third the capacity of the Vaal Dam. The likely possible combined annual water yield from the mine void amounts to some 150 Megalitres per day (Mℓ/d) to potential consumers. For comparison, Rand Water currently supplies approximately 4 000 Mℓ/d. Although the annual volume of void water is very small in the context of the Vaal River System and the supply volume of Rand Water, the salt load introduced into the Vaal River System from the mine void is disproportionately large, necessitating removal of salts prior to release into this system.

Table 1.1: Comparison of the Vaal Dam, estimated mine voids and annual pumping rates

Water Bodies	Million m^3
Vaal Dam	
Capacity (volume)	2 570
Average inflow (per annum)	1 400
High inflow observed (per annum)	7 605
Basins (estimated)	
Western	43
Central	467
Eastern	304
Total	814
Proposed maximum pumping rate from mine voids (per annum)	
Western*	22
Central	18
Eastern	37
Total	77
Rand Water Board water supply (per annum)	1 497

* This is the required pumping rate considered to empty the shallow aquifer in one year

Whilst it is not the scope of this component of the Feasibility Study to assess the economic and engineering viability of all options, it is important to be cognisant of the potential cost impact of various options for addressing the AMD issues to allow options to be screened for further study. The central considerations of this component, principally the volume and quality of the mine void water and abstraction aspects (e.g. time to surface decant and critical water levels without intervention, minimum pumping volumes, potential variations in water quality with depth, interconnectivity of the mine void), all inform the viability of various options for further investigation in the options analysis component of the study. Such additional options include pumping from shallower depths at multiple sites, and natural or controlled/engineered decant, i.e. tunnel or siphon abstraction.

The scope of this report does not include a comprehensive review of shaft selection criteria, but does aim to comment on shaft selection as it pertains to connectivity to the mine void, specifically considering the following aspects:

- Connectivity to the shallow mine void (to maximise the potential of flushing the system with ingress of surface water and reduce the risk of drawing potentially poor quality water from depth);and
- Connection to the mine void on multiple levels (to minimise the risk of collapse on an individual level).

A critical consideration of this study is whether the basis for the STI to address the AMD problem is accurate and appropriate. This is defined by the TCTA Due Diligence Report (2011) and associated appendices, “Witwatersrand Gold Fields: Acid Mine Drainage (Phase 1)”, issued in August 2011 by BKS (Pty) Ltd on behalf of the TCTA (2011).

The status quo assessment of the AMD situation in the Witwatersrand according to the TCTA (2011) is taken as the baseline for the Feasibility Study, and any points of departure from this assessment are described in detail.

1.2 Methodology

In order to effectively review the basis for the STIs (particularly of the ECLs, water qualities, etc.) as defined by the TCTA (2011), it was necessary to establish a dataset that is as complete and current as possible. The data were then independently assessed to derive predictions of surface and subsurface decant times, water qualities, ingress and pumping volumes. **Figure 1.1** illustrates the methodology applied in this study.

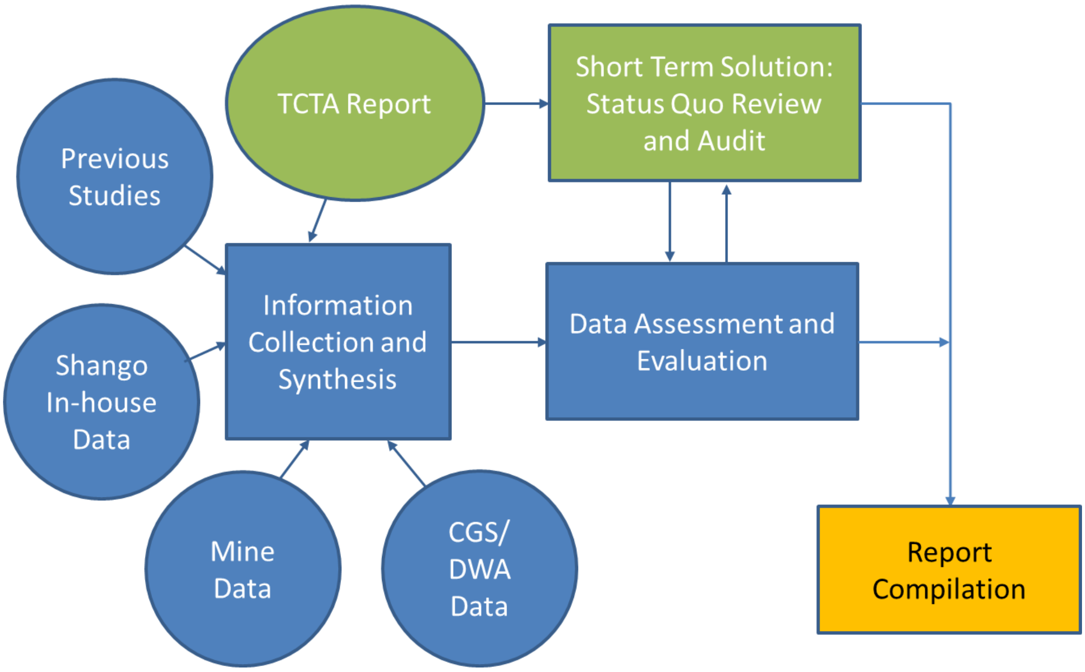


Figure 1.1: Illustration of the methodology used in this project

1.3 Data Utilised

The data necessary for this study includes the key components highlighted in **Figure 1.2.** General internet and reference searches were undertaken to add to the extensive public domain information already available. Internet sources such as industry news, academic, company and state websites were interrogated. Once an inventory of available data availability was compiled, information considered significant to the study was identified and sourced.

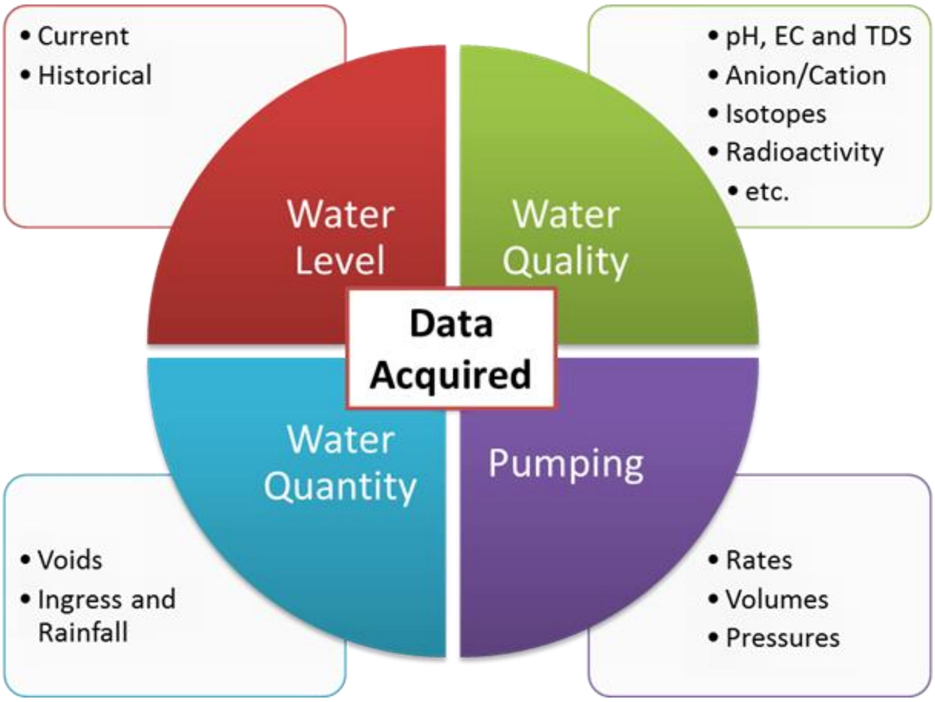


Figure 1.2: Illustration of the data acquired for this study

The study team has collected extensive datasets across the basins for other studies over the past eight years. Gaps in these datasets were identified and then explored. Where information was not readily available, workshops were held with various stakeholders and experts in an effort to address these gaps, which has enabled a comprehensive database to be established. **Table 1.2** lists the main contributors during the project to date. The data from the Golder/BKS feasibility studies for the Western Utilities Corporation (WUC) was also supplied to the team.

Table 1.2: Sources of data acquired

Company	Source	Basin	Water Data				General Data		
			Quality	Quantity	Level	Pumping	Spatial	Literature	Rainfall
DWA	Eddy Van Wyk	Central, East and West Rand	☑	☐	☑	☐	☐	☐	☑
CGS	Henk Coetzee	West Rand	☑	☑	☑	☑	☑	☑	☐
Shango Solutions	In-house Database	Central, East and West Rand	☑	☑	☑	☑	☑	☑	☐
Gold One	Richard Stewart	East Rand and West Rand	☐	☐	☑	☐	☑	☐	☐
Rand Uranium	Basie van der Walt	West Rand	☑	☑	☑	☑	☐	☐	☐
Wits University	Prof Terence McCarthy	East Rand	☑	☑	☐	☑	☐	☑	☐
The Weather Service	General personnel	Central, East and West Rand	☐	☐	☐	☐	☐	☐	☑
CSIR	Phil Hobbs	West Rand	☑	☐	☐	☐	☑	☑	☐
WRC	WRC	Central, East and West Rand	☑	☑	☑	☑	☐	☑	☐
Goortvlei	R. Scott	Central and East Rand	☑	☑	☑	☐	☐	☑	☐
ERPM/DRD	Vivian Labuschagne	Central Rand	☑	☑	☑	☑	☐	☐	☐
North West University	Frank Winde	Central Rand	☐	☑	☑	☐	☑	☐	☐
SRK/Aurecon	SRK/Aurecon	Central, East and West Rand	☐	☐	☐	☐	☐	☑	☐
Camden Geoserve	Peter Camdem-Smith	Central Rand	☐	☐	☑	☑	☐	☐	☐

For the assessment of surface water ingress, the most relevant data and information that was reviewed is tabulated in **Table 1.3** below.

Table 1.3: Summary of data reviewed for the assessment of surface water ingress

Report Title	Authors and Date	Brief Summary
Witwatersrand Gold Fields Acid Mine Drainage : Contract TCTA 08-041 Water Balance and levels	BKS in association with Golder Associates, (2011)	Status quo of expected water levels and summary of water balance for Witwatersrand goldfields
Western Utilities Corporation (WUC) – DFS Resource Estimation in the West Rand Basin	Golder Associates, (2009)	Summary report and water balance based on previous work related to water volumes entering the underground workings in the West Rand Basin
Western Utilities Corporation (WUC) – DFS Resource Estimation in the Central Rand Basin	Golder Associates, (2009)	Summary report and water balance based on previous work related to water volumes entering the underground workings in the West Rand Basin
Western Utilities Corporation (WUC) – DFS Resource Estimation in the East Rand Basin	Golder Associates, (2009)	Summary report and water balance based on previous work related to water volumes entering the underground workings in the West Rand Basin
Ferret Mining & Environmental Services (Pty) Ltd. A strategic Water Management Plan for the Prevention of Water Ingress into Underground Workings of the Witwatersrand Basin-Phase 1.	Boer et al., (2004)	Study to determine the main sources of water ingress and the possible measures to prevent water ingress into the mine workings
Report to the Inter-Ministerial Committee on Acid Mine Drainage – Mine Water Management in the Witwatersrand Gold Fields with special emphasis on Acid Mine Drainage.	Expert Team of the Inter-Ministerial Committee (2010)	Study to determine impacts and possible solutions to the AMD problems for the Western, Central and Eastern basins
Witwatersrand Gold Fields Acid Mine Drainage – Due Diligence Report by BKS (Pty) Ltd, BKS Report no J01599/05	BKS in association with Golder Associates (2011)	Study to determine possible ways of decreasing the AMD problem
Sustainable Development through Mining – West Rand Goldfield:	Coetzee and Van Tonder (2011)	Study to determine possible remediation measures to decrease the ingress of

Report Title	Authors and Date	Brief Summary
Regional Closure Strategy.		surface water into the mine workings
Sustainable Development through Mining – Regional Closure Strategy: Central Rand Goldfield.	Strachan *et al*. (2011)	Study to look at short- and long-term measures to reduce the ingress of surface water into the mine workings as part of mine closure planning
Sustainable Development through Mining – Regional Mine Closure Strategy: East Rand Basin	Mafanya and Esterhuyse. (2011)	Study to give guidance on future mine closure strategies regarding the control and management of AMD
Desktop assessment of the risk for basement structures of buildings of Standard Bank and Absa in Central Johannesburg to be affected by rising mine water levels in the Central Basin	Winde *et al*. (2011)	Study undertaken by the Mine Water Research Group NWU and includes in depth assessment of possible ingress sources to Central Basin

2 STATUS QUO AS DEFINED BY PREVIOUS WORK

The parameters pertaining to the AMD volumes and qualities, as well as surface decant and ECL levels as quoted in the IMC (2010) report and the TCTA (2011) report are summarised in **Table 2.1** to **Table 2.3**.

Table 2.1: Water yields per basin

Basin	Approximate Average * Pumping Volume	Approx. Pumping Range
	Mℓ/d	Mℓ/d
Western	27	23-35
Central	57	34-84
Eastern	82	38-110

* *Based on pumping 19 hr/d*

Table 2.2: AMD water chemistry

Water Chemistry Variable	Units	IMC (2010) report			TCTA (2011) report		
		Western	Central	Eastern	Western	Central	Eastern
		(Median, Harmony)	(Inflow, Scott, '95)	Median, CGS	(95^{th} percentile)	(95^{th} percentile)	(flooded condition)
TDS	mg/ℓ	6 580	4 936 [(b)]	2 041	7 174	7 700	5 500
Conductivity	mS/m	510	467 [(a)]	246	548	730	450
Calcium (Ca)	mg/ℓ	-	-	-	461	580	550
Magnesium (Mg)	mg/ℓ	-	-	-	345	380	230
Sodium (Na)	mg/ℓ	-	-	-	139	150	325
Sulphate (SO_4)	mg/ℓ	4 010	3 700	1 037	4 556	5 200	3 275
Chloride (Cl)	mg/ℓ	-	-	-	65	260	260
pH	-	-	-	-	3.4-4.0	2.3 [(c)]	5
Acidity ($CaCO_3$)[(d)]	mg/ℓ	-	-	-	2 560	2 425	750
Iron (Fe)	mg/ℓ	697	112	38	933	1 000	370
Aluminium (Al)	mg/ℓ	-	-	-	54	50	1
Manganese (Mn)	mg/ℓ	-	-	-	312	60	10
Uranium (U)	mg/ℓ	-	-	-	0.2	--	--

[a] Derived from TDS/EC ratio of 10.6, [b] Derived by summation of reported salts
[c] 5^{th} percentile, [d] Calculated.

Table 2.3: Water level summary table of the Western, Central and Eastern basins

Source Document	Decant Level (m amsl)	Decant Point	ECL (m amsl)	Proposed Target Operating Level (m amsl)	Depth of Proposed TOL (m) below lowest decant point	Rationale for Proposed TOL	Level not to be exceeded (e.g. bottom of aquifer)	Surface level at location of feature to be protected (m amsl)	Depth from surface to feature to be protected (m)	Other Considerations	Abstraction Shaft	Abstraction Shaft Collar Level (m amsl)	Depth of proposed TOL at Abstraction Shaft (m)
Western Basin													
IMC report (Dec 2010)[1]	1 680	Black Reef Incline & 18 Winze and 17 Winze	1 530	1 530	150	Protection of dolomitic groundwater in the Cradle of Humankind	Not given	Not given	Not given	None given	Not given	Not given	Not given
	Not given in report, calculated from depth and ECL. 1 530 + 150 = 1 680	Chapter 6.4.1, page 49, first paragraph	Table 7.4, page 65	Not defined, assumed to be equal to ECL of 1 530 m amsl	Table 10.1	Table 10.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TCTA Due Diligence Report (2011)[2]	1 680	Black Reef Incline & 18 Winze and 17 Winze	1 600	1 550	130	50 m below base of dolomite outlier. If the mine water pumping level is maintained below the base of the dolomite outlier, groundwater flow will be towards the mine and seepage towards the Sterkfontein dolomite will be minimised.	1 600	Not given	Not given	None given	Rand Uranium Shaft No. 8	1 715.3	165.3
	Table 1, page 10	Table 1, page 10	Assumed to be level quoted for the base of the dolomite	Reported as ECL 50 m below base of dolomite	Decant Level minus TOL	Table 1 of report and Chapter 2 of Annexure B	Annexure B	N/A	N/A	N/A	Chapter 6.3.1	Table 11	Shaft No. 8 Collar Level - TOL
Central Basin													
IMC report (Dec 2010)[1]	Not given	Decant will occur in low-lying areas in the vicinity of the ERPM Mine in Boksburg and possibly elsewhere across the Witwatersrand.	1 503	1 503	Not given	Protection of dolomitic aquifer south of Boksburg	Not mentioned	Not given	Not given	Possible mining by CRG (bottom p 24, p 65)	Not specified	Not specified	Not specified
	N/A	Page 25	Table 7.4, page 65	Not defined, assumed to be equal to ECL of 1 503 m amsl	N/A	Table 10.1	N/A	N/A	N/A	Gold Reef City Tourist Attraction (Table 10.1)	N/A	SVW collar level calculated as 1 653 m masl from ECL at SWV of 150 m	Page 65 gives depth to ECL at SWV as 150 m

Source Document	Decant Level (m amsl)	Decant Point	ECL (m amsl)	Proposed Target Operating Level (m amsl)	Depth of Proposed TOL (m) below lowest decant point	Rationale for Proposed TOL	Level not to be exceeded (e.g. bottom of aquifer)	Surface level at location of feature to be protected (m amsl)	Depth from surface to feature to be protected (m)	Other Considerations	Abstraction Shaft	Abstraction Shaft Collar Level (m amsl)	Depth of proposed TOL at Abstraction Shaft (m)
TCTA Due Diligence Report (2011)[2]	1 617	Cinderella East	1 517	1 467	150	Protection of the weathered and fractured aquifers within the basin	1 567	Not given	Not given	Mining by CRG down to a level of 1 278 m amsl (400 m below surface at the CRG Portal)	South West Vertical Shaft	1 653.24	186.24
	Table 1, page 10	Table 1 gives C. East as the decant point. Note - On p. 47 collar level for C. West is given as 1 614 m amsl, which is 3 m lower than C. East.	Table 1 gives ECL 1 467 and Annexure B states that this includes 50 m buffer. Thus ECL of 1 467 equates to TOL.	Annexure B states that ECL includes 50 m buffer. Thus TOL 50 m below ECL of 1 517	Decant level minus TOL	Table 1, page 10	Annexure B: "These aquifers generally only extend 80-100 m below the surface providing a 50 m buffer to ensure the protection of these groundwater resources.". Level of aquifer thus assumed to be 50 m above ECL.	N/A	N/A	Chapter 7.2.3 p. 57	Table 26, p. 53	Table 24, p. 49. Collar level subsequently resurveyed by DWA as 1 699 m amsl	SWV Collar Level minus TOL
Eastern Basin													
IMC report (Dec 2010)[1]	1 550	Predicted decant point being within the town of Nigel	1 150	1 150	400 m below probable decant point at Nigel	Prevention of the rise of mine water into the overlying dolomitic aquifer	Not mentioned	Not given	Not given	None given	Not specified but assumed as Grootvlei No. 3 Shaft	Not given	Not given
	Not given, calculated from given ECL and depth of ECL at Nigel	Bottom of Page 25	Table 7.4, page 65	Not defined, assumed to be equal to ECL of 1 150 m amsl	Table 10.1, page 89	Table 10.1, page 89	N/A	N/A	N/A	N/A	Top of p 64 - "assistance to Grootvlei Mine should be continued to allow pumping to continue and the infrastructure to be maintained"	N/A	N/A
TCTA Due Diligence Report (2011)[2]	1 549	Nigel No. 3 Shaft	1 280	1 280	269	ECL set below the base of the dolomitic formations in the Eastern Basin for protection of the dolomitic groundwater resources.	1 280	Not given	Not given	Possible mining by Gold One down to 1 040 m amsl	Grootvlei No. 3 Shaft	1 570	290
	Table 1, page 10	Table 1, page 10	Table 1, page 10	Not defined, assumed to be equal to ECL of 1 280 m amsl	Decant level minus TOL	Table 1, page 10	Annexure B: "The base of the dolomite, according to Scott (1995), is at an elevation of 1 280 m amsl"	N/A	N/A	Chapter 8.2.4, page 92	Chapter 8.3.2, page 94	Chapter 8.3.2, page 94	No. 3 Collar Level minus TOL

Note: In the work of the IMC and TCTA the term ECL was used to define the proposed status water level which is now termed Target Operating Level.

2.1 Abstraction Point Selection

The TCTA (2011) identified shafts for pumping for the STI (**Table 2.3**) based on an assessment of the following criteria:

- Infrastructure already available;
- Pumping infrastructure;
- Treatment plants and proximity to sludge disposal sites;
- Bulk services including electricity;
- Land availability and ground stability for plant infrastructure;
- Shaft barrel stability;
- Connectivity to mine void.

Inclined shafts were not considered in the TCTA Due Diligence Report (2011). The reason for this was not explicitly described, although it is believed that pump equipment selection was the main factor.

3 GEOLOGICAL AND HYDROGEOLOGICAL SETTING OF THE WITWATERSRAND BASIN

3.1 Geology and Mining

The Western, Central and Eastern basins are the oldest mining districts of the greater Witwatersrand Basin, a more or less oval-shaped depression about 300 km long and 200 km wide (**Figure 3.1**). The depression hosts the Witwatersrand Supergroup, an approximately 7 km thick sequence of sedimentary rocks, amongst which are layers of gold-bearing conglomerate. These conglomerates, or reefs, have been mined for gold since their discovery in 1886. The ca. 2 900 million year old Witwatersrand Supergroup is divided into the lower West Rand Group (about 5 km thick), which consists of equal proportions of quartzite (formerly sandstone) and shale (formerly mudstone), and the upper Central Rand Group (about 2 km thick) which consists primarily of quartzite with numerous conglomerate layers, several of which contain gold in economically extractable quantities (**Figure 3.2**).

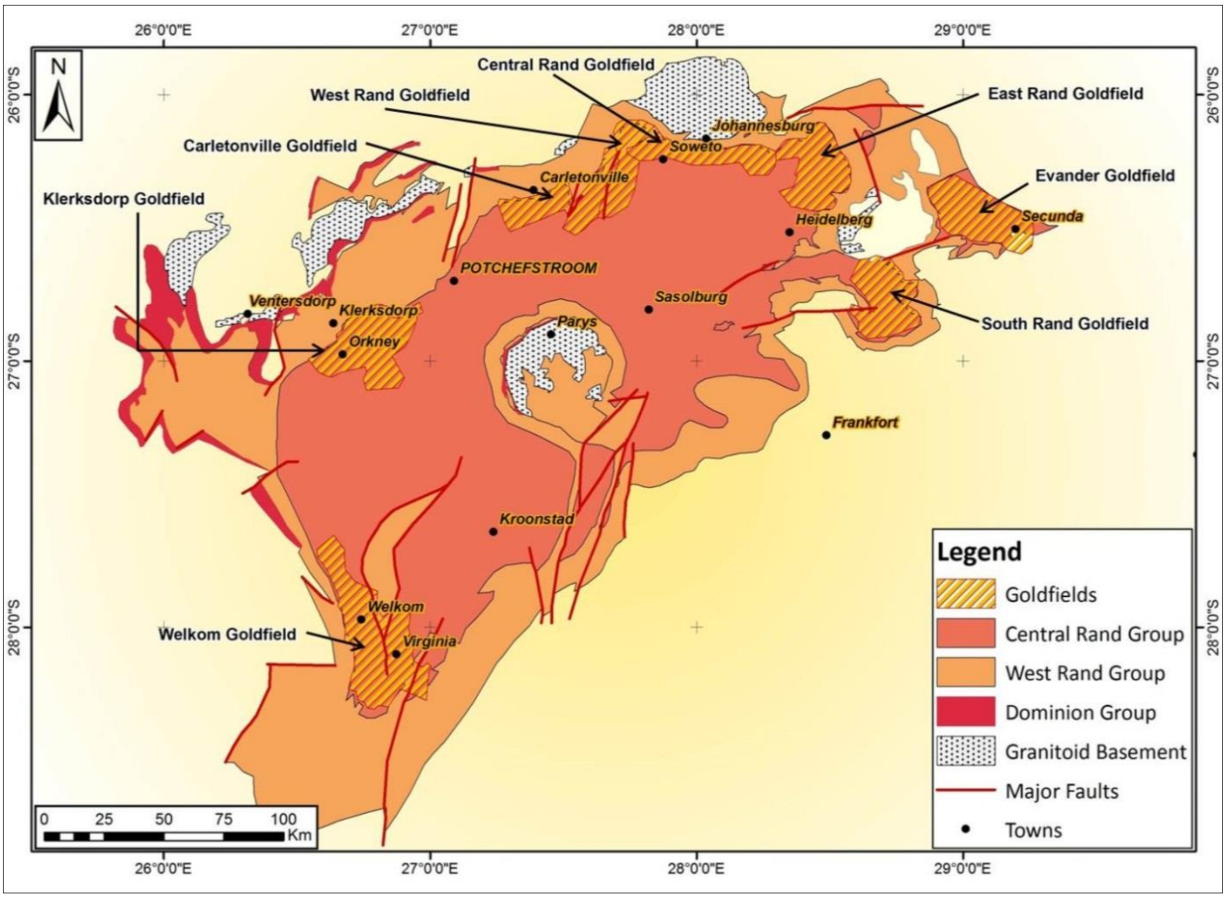


Figure 3.1: Simplified geological map of the Witwatersrand Basin showing the location of the main goldfields

Rocks of the Witwatersrand Basin are overlain by several generations of younger rock formations. The oldest of these is the Ventersdorp Supergroup (2 700 million years old), consisting of a variety of rock types of which the volcanic rock, basalt, represented by the Klipriviersberg Group, is the most important. Locally the basalt is separated from the underlying Witwatersrand Supergroup by a gold-bearing conglomerate (the Ventersdorp Contact Reef (VCR)). The Witwatersrand and Ventersdorp supergroups are overlain by sedimentary rocks belonging to the Transvaal Supergroup (about 2 600 million years old). A variety of different sedimentary rock types form this lithostratigraphic unit, the most important of which are quartzite and conglomerate, which is locally gold-bearing (the Black Reef Formation), followed by a thick layer of dolomite (the Chuniespoort Group). Finally, all of these older rock sequences are overlain by sandstones and mudstones of the Karoo Supergroup (about 300 million years old). The Karoo sequence also contains layers of coal (the Ecca Group), some of which are economically exploited in the area of the Witwatersrand Basin, including the Eastern Basin. These post-Witwatersrand rock sequences all contribute to the complex geology of the northern portion of the Witwatersrand Basin in one way or another.

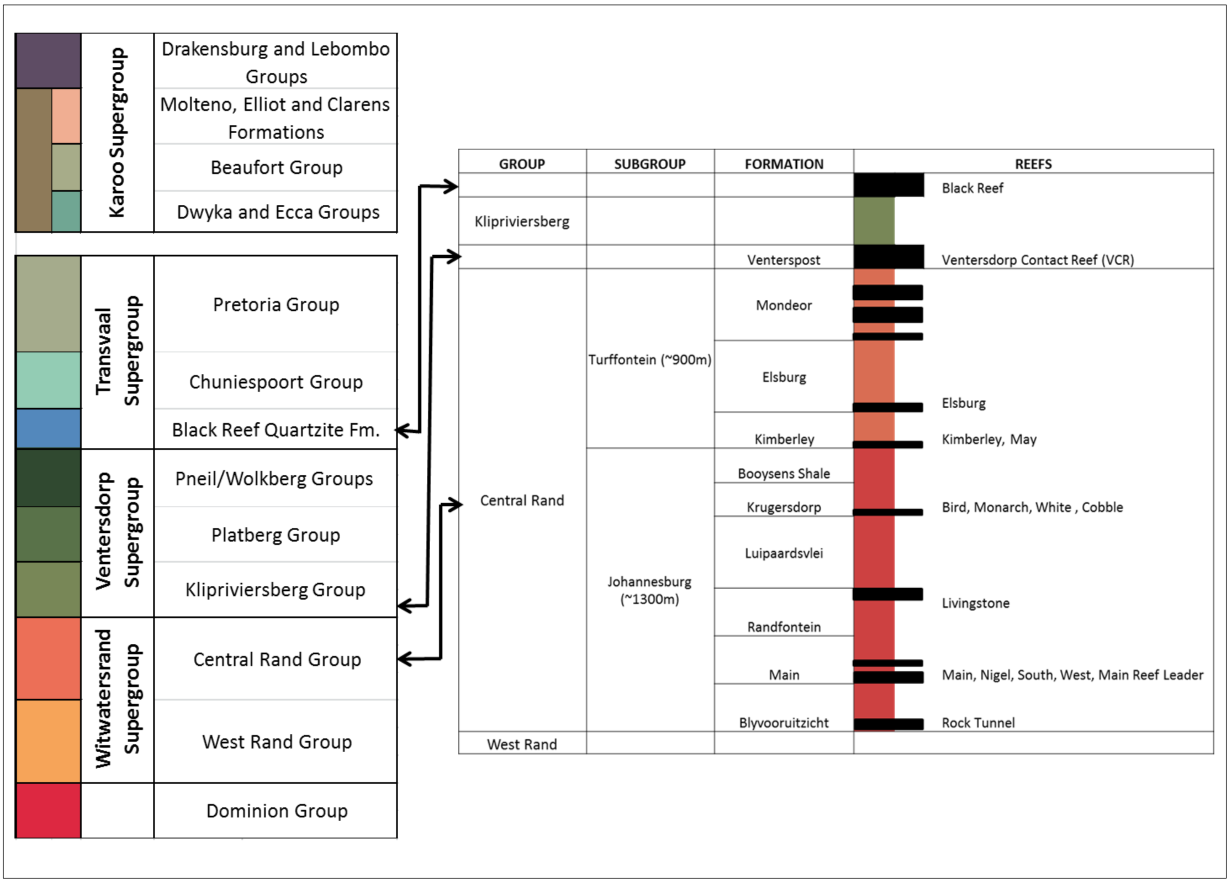


Figure 3.2: Simplified stratigraphic column for the northern goldfields, highlighting the principal reefs mined in the Western, Central and Eastern basins

As mentioned above, gold-bearing conglomerates are confined to the Central Rand Group (**Figure 3.2**). Along the northern portion of the Witwatersrand Basin, where the Western, Central and Eastern basins are situated, most of the gold was contained in conglomerate layers located near the base of the Central Rand Group (the so-called Main Reef group of conglomerates), which included the Main Reef Leader, Main Reef, South Reef and equivalents. About a third of the way up through the sequence, the Bird Reef conglomerate contained sporadic gold, and about two thirds from the base the Kimberley Reef conglomerate was also sporadically mined (**Figure 3.2**). Finally, mining of the overlying VCR and Black Reef Formation conglomerate was also locally carried out. All of these conglomerate beds contained about 3% of the mineral pyrite (iron sulphide). Gold extraction procedures used on the mines do not extract the pyrite and it reports to the various types of mine residue deposits. It is this pyrite which is the source of AMD along the Witwatersrand and elsewhere.

In addition to gold, uranium is also a potentially economic commodity in the Witwatersrand Basin. The Western Basin is the only one of the three basins under consideration to contain significant economically exploitable uranium, notably the Monarch Reef. From 1952 to 1995, approximately 28 000 tonnes uranium were produced from mines in this basin. Although uranium is present in the Central Basin, grades were too low to warrant economic extraction. The Eastern Basin only produced about 4 200 tonnes of uranium, mainly from the Kimberley Reef horizons (Cole, 1998).

The conglomerate layers of the Central Rand Group were laid down sequentially over a period of tens of millions of years. Each conglomerate was originally deposited as a gravel-covered plain hundreds of square kilometres in extent that formed as the rivers, draining the hinterland to the north, coalesced in the slowly subsiding Witwatersrand Basin. For example, the Main Reef was once a continuous gravel-covered plain extending from what is now Randfontein in the west to beyond Springs in the east and south to Heidelberg, an area in excess of 3 000 km^2. The Witwatersrand strata were subjected to various tectonic forces as the basin gradually filled and the once continuous strata became warped, tilted and fragmented by faults. Great fissures formed across the sedimentary layers at various times and molten rock flowed upwards through these fissures, erupting on surface to form extensive layers of volcanic rock, such as found in the Ventersdorp Supergroup. The fissures are now represented by dykes, some of which are tens of metres wide. Long periods of erosion also took their toll. Two periods of erosion were particularly destructive, the first preceding the deposition of the Black Reef Formation conglomerate (Transvaal Supergroup), and the second preceding the deposition of the coal-bearing sandstones of the Karoo Supergroup.

The Witwatersrand rocks that are observed today are thus remnants of a much more extensive cover of gold-bearing sedimentary layers. Although originally horizontal, they are now inclined, sometimes even dipping vertically. Large areas of Witwatersrand strata are buried beneath younger rocks, especially in the Western and Eastern basins (**Figure 3.3**).

The fragmentation of the Witwatersrand rocks is far more evident if the younger Transvaal and Karoo supergroup strata are removed (**Figure 3.1**), as most of the disruption occurred prior to the deposition of the cover rocks.

The conglomerate layers of the Central Rand Group along the northern portion of the Witwatersrand Basin are broken into three discrete domains: the Western Basin, which is separated from the Central Basin by a fault-bounded block of conglomerate-free West Rand Group (the Witpoortjie Horst), and the Eastern Basin, which is separated from the Central Basin by an arch-like structure over which conglomerate was very poorly developed (the Van Dyk Anticline and Springs Monocline, generally referred to as the Boksburg Gap). There is therefore no interconnectivity of the mine void between these basins. In each of these domains, the layers of conglomerate, typically no more than a metre thick, were mined and the rock brought to surface where the gold was extracted.

The number of conglomerate layers mined varied from domain to domain: in the Western Basin, some twenty separate conglomerate layers were mined, some extensively, others only sporadically; in the Central Basin, four were mined in the west, reducing to only one in the east; and in the Eastern Basin, one was very extensively mined (the Main or Nigel Reef) and a second (the Kimberley Reef) more sporadically exploited. Locally, mining of the Transvaal-age Black Reef Formation also occurred. Mining of the conglomerate layers extended to a vertical depth of more than 3 km below surface on certain mines in the Central Basin.

The extraction of the conglomerate layers left a huge void, which was continuous where the layers were well mineralised, broken only by dykes and smaller fault off-sets that could not be mined. However, much of the void has probably collapsed or in the deeper levels has closed by slow creep (plastic flow), substantially reducing the void volume (Winde *et al*., 2011). Brittle collapse of the shallower workings does not reduce the void volume but rather distributes it amongst smaller voids. The filling of the main mining voids with water has become the focus of intense scrutiny.

It must also be noted that there are reefs where limited mining took place which are isolated from the main voids and will fill as independent sub-basins. The number of such isolated sub-basins is unknown and can only be determined by detailed examination of mine plans held by the Department of Mineral Resources (DMR).

Many of these small voids may not actually decant. In order for decant to occur, it is necessary that the natural water table somewhere in the void ingress area should lie at a higher elevation than a shaft collar or other opening to the void. On horizontal ground, therefore, the water level in the shafts accessing the void will rise to the water table and no further. In cases where ingress volumes are small, shaft water may decant into the ground water and never appear on surface. Therefore, each of these isolated voids will behave differently and once identified, each will have to be considered on its merits.

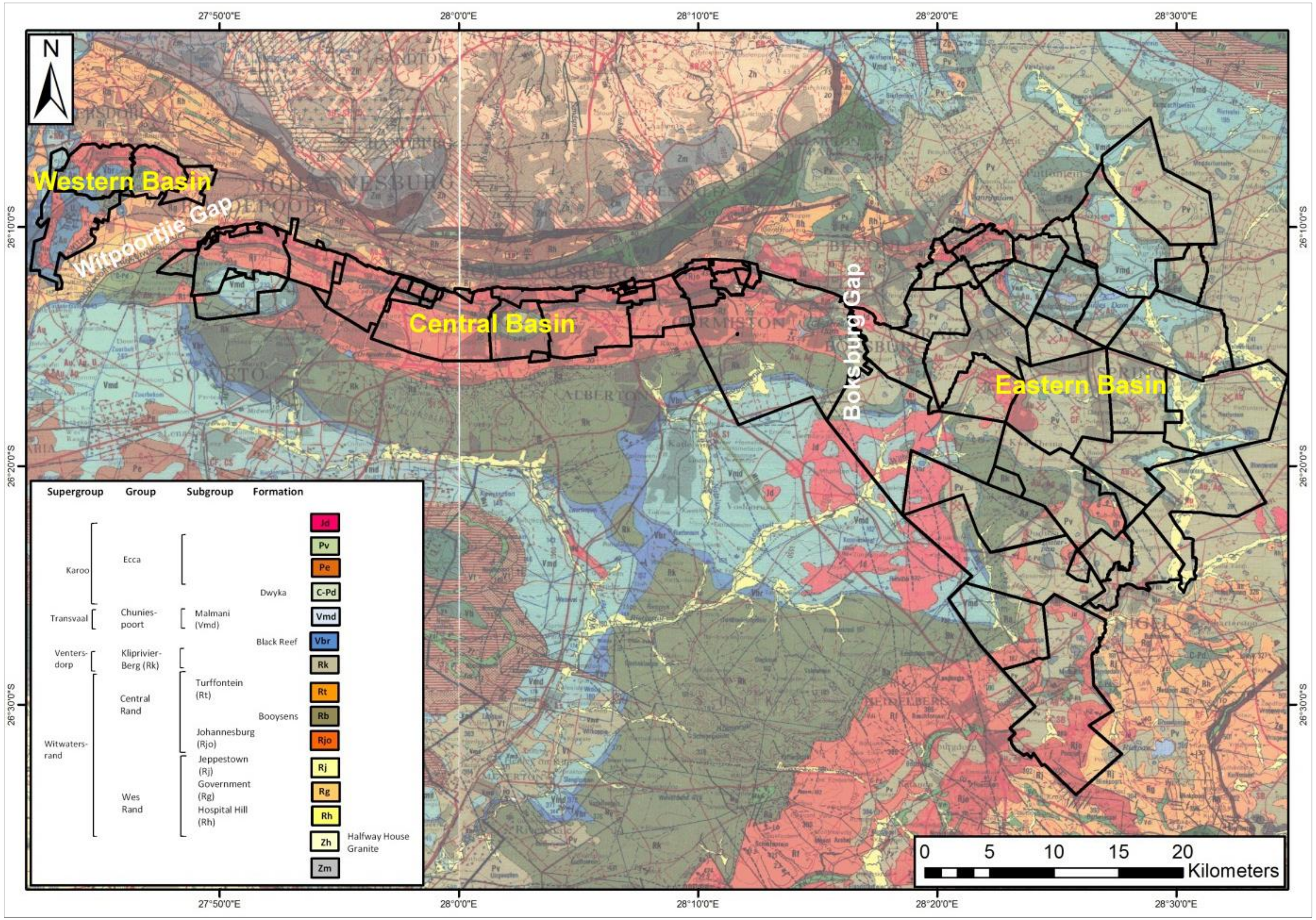


Figure 3.3: The northern extent of the Witwatersrand Basin in the Randfontein-Johannesburg-Nigel area, showing mine boundaries of the Western, Central and Eastern basins

3.2 Hydrogeology

The regional hydrology and hydrogeology is controlled by the outcropping quartzitic rocks of the Witwatersrand Supergroup that form a continental divide separating rivers flowing northwards towards the Limpopo River (and discharging to the Indian Ocean), from the rivers draining southwards to the Orange River (discharging to the Atlantic Ocean). All the mining occurred on the southern side of the continental divide, with the result that most of the impacted water resources (rivers and groundwater) occur in the Vaal River catchment.

With the exception of the Transvaal Supergroup dolomite, none of the other rock types described above (**Section 3.1**) are considered as significant aquifers. Most groundwater occurrences are restricted to the shallow weathered zones across all formations and structural features (dyke contacts, fractures and faults) which can form preferential groundwater flow paths (WUC, 2009). Nevertheless, water from these shallow, weathered, minor aquifers is also extracted for domestic and agricultural use via boreholes at depths up to 100 m below ground level. Groundwater flow in the shallow weathered aquifer mimics the topography and daylights as springs above less permeable layers, discharging as base flow to the streams and rivers. Infiltration of precipitation recharges the shallow weathered aquifer (usually estimated at around 5% to 7% of the mean annual precipitation).

A study done on the dolomitic rocks of the Transvaal Supergroup in the Far West Rand identified that the geological structure of the formation is highly variable, and are karstic due to the erosion and dissolution of the carbonate rocks along joints and fractures (Schwartz and Midgley, 1975). This process has resulted in substantial water-storage potential and the dolomite aquifer is considered a significant water resource, exploited extensively for domestic and agricultural usage. The volume of water contained in the dolomite varies per square kilometre, and this effect is shown in the presence of depressed water tables as indicative of dewatered areas, and elevated water tables as recharge areas, which creates local high points in the water table (Schwartz and Midgley, 1975). Where the dolomite is outcropping in the Western and Eastern basins and in hydraulic connection with the mined out voids, the dolomitic aquifers can contribute a significant component of the total ingress.

When mining ceases, the mine voids re-water, resulting in the formation of an artificial “aquifer” in the tunnels, drives and shafts. The vertical hydraulic connectivity of the mine voids with the overlying shallow weathered aquifer and structures is limited, as indicated by field observations where the depth to the water table is still in the order of 3 m to 17 m below surface, indicating that the weathered aquifer is not completely dewatered (WUC, 2009). However, the mine void acts like a sump and depressurisation of the groundwater bearing zones/structures when intersected by mining, results in a flow gradient towards the void. Fissures bearing significant water were often sealed by grouting to restrict ingress.

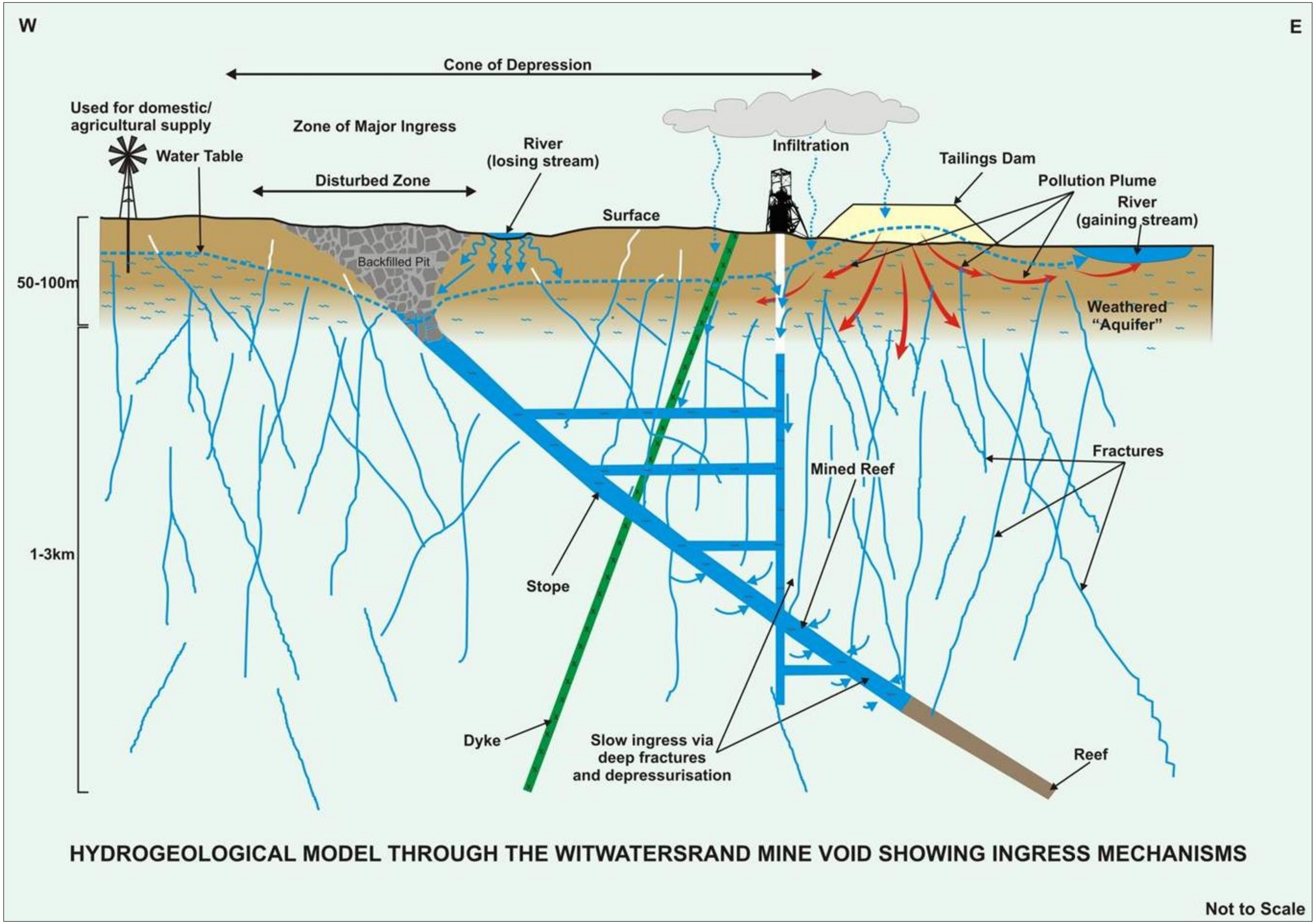


Figure 3.4: Schematic illustration of a conceptual hydrogeological model for the Witwatersrand Goldfield

4 METEOROLOGY AND INGRESS

4.1 Rainfall

Rainfall data were analysed based on the available record from October 1921 to October 2010. The main aim of this analysis was to review the historical rainfall pattern over time. The figures below cover all three basins in the study area and show the distribution of rainfall in the 90 year period of record. It is noted that no significant change occurred over time except in 1975 when severe flooding occurred in most parts of Johannesburg. **Figure 4.1** is a table indicating the average rainfall over 10 year intervals, from which the average rainfall for each year is calculated. It is noted that the long-term mean annual precipitation amounts to 694 mm for the Johannesburg area.

Period					Month												Per Decade
					Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Oct	1921	to	Sept	1931	58.5	99.9	98.1	127.7	95.8	92.5	33.5	18.4	6.9	13.7	7.6	26.5	679.3
Oct	1931	to	Sept	1941	43.2	112.3	124.7	112.2	95.8	82.0	38.0	28.2	6.8	7.5	9.0	21.1	680.8
Oct	1941	to	Sept	1951	72.9	96.9	117.8	112.2	101.1	91.5	42.5	24.5	10.5	11.7	5.3	14.7	701.5
Oct	1951	to	Sept	1961	59.9	122.3	113.2	114.6	108.4	74.5	58.7	23.6	6.3	8.8	4.4	29.6	724.4
Oct	1961	to	Sept	1971	74.6	103.3	105.4	128.1	75.8	76.5	66.1	17.1	8.3	4.0	5.5	17.7	682.3
Oct	1971	to	Sept	1981	67.5	110.0	104.1	172.5	94.9	75.2	39.3	13.2	4.2	4.9	9.1	28.3	723.3
Oct	1981	to	Sept	1991	81.2	101.3	116.3	101.4	83.4	92.4	35.5	4.3	11.7	2.8	8.8	25.3	664.3
Oct	1991	to	Sept	2001	82.7	113.2	126.2	113.9	115.3	99.2	36.4	24.9	4.4	0.8	5.2	20.9	743.0
Oct	2001	to	Oct	2010	54.4	78.5	116.0	161.4	85.4	79.2	36.8	12.1	9.4	1.4	6.4	8.2	649.3
MAP																	**694.2**

Figure 4.1: Rainfall per decade over time

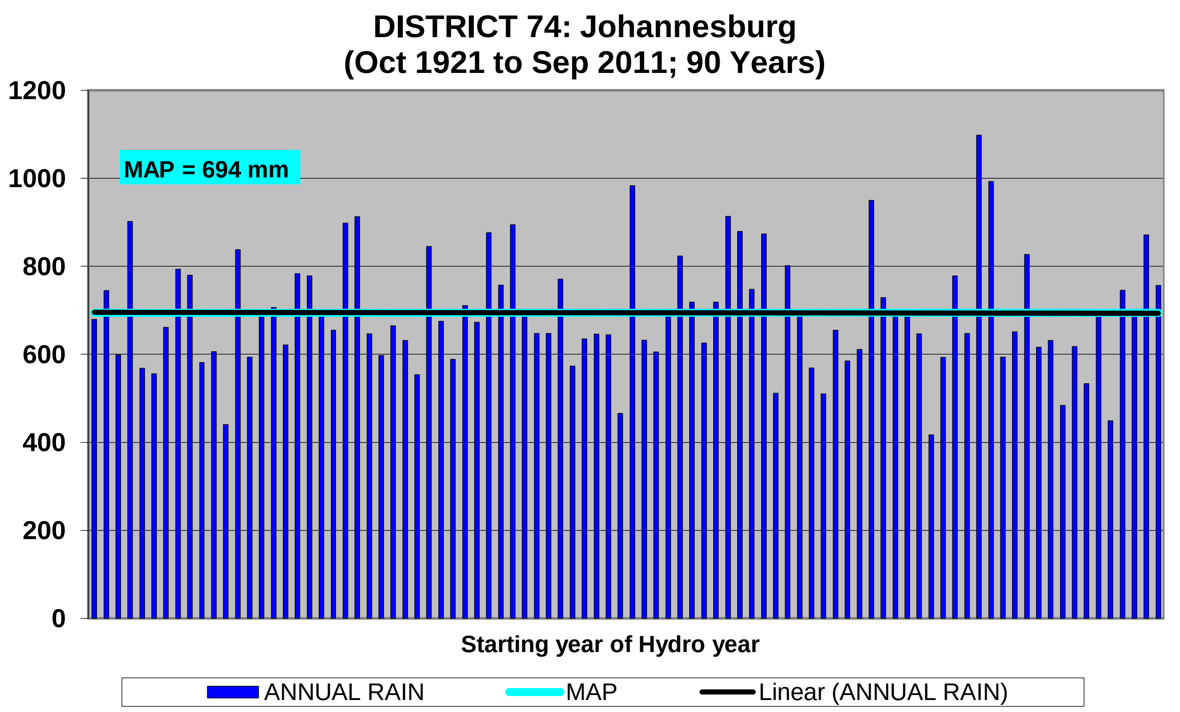


Figure 4.2: Long-term annual rainfall pattern for Johannesburg

As an independent validation of the rainfall data presented in the WUC (2009) report, selected weather station data were reviewed for each basin (**Figure 4.3**). These stations and analyses are documented in the individual basins' sections of this report (**Sections 6.5.1, 7.5.1**, and **8.5.1**).

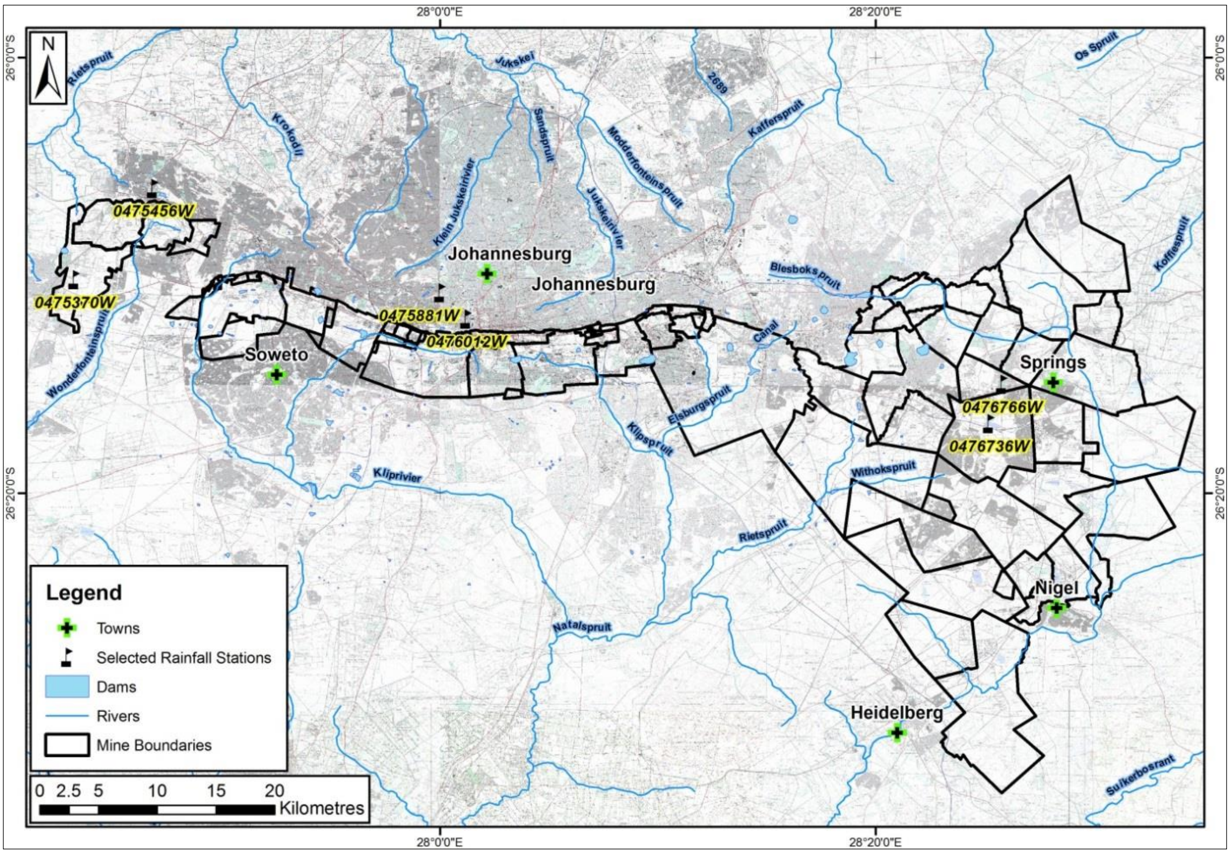


Figure 4.3: Selected weather stations across the basins used for verification of rainfall data

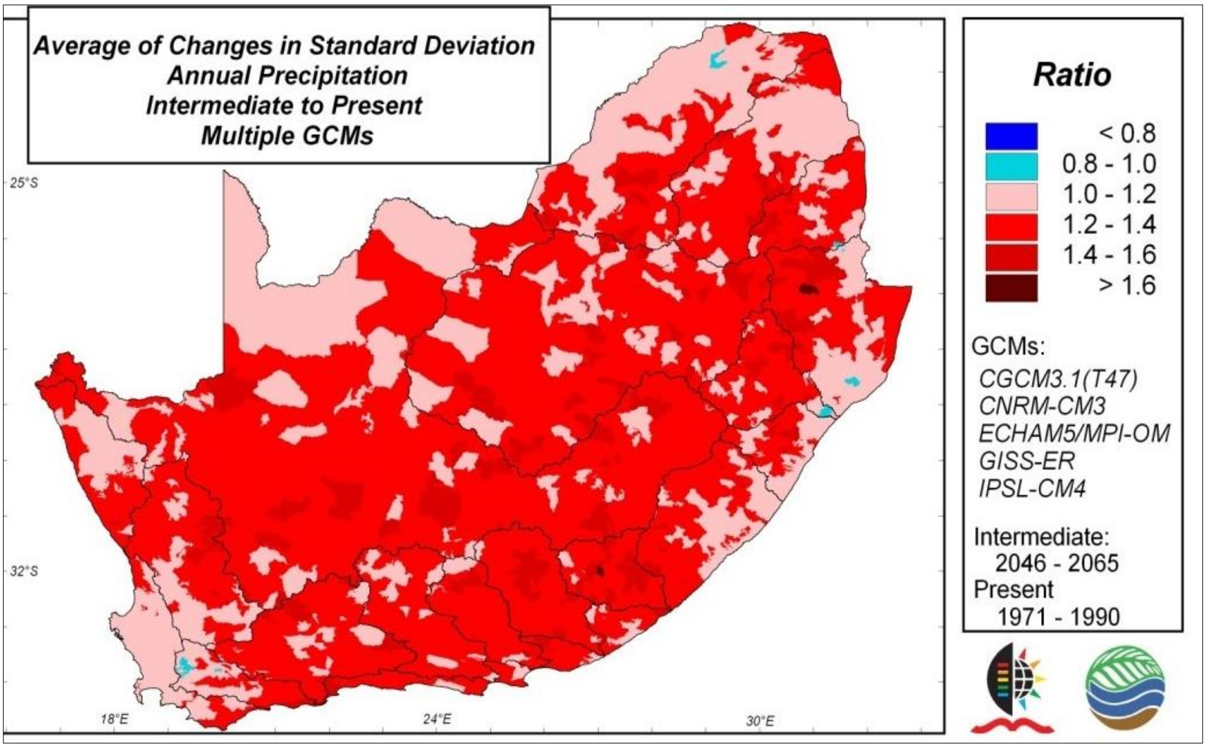
4.2 Climate Change

An important factor to consider is potential climate change that may affect weather patterns, as well as deviations in rainfall. The University of KwaZulu-Natal (Schulze, 2010) has recently conducted a study to determine the potential deviations in rainfall in the southern African region. The study was based on the Global Climate Model (GCM), which was then downscaled to cover southern Africa. The results are shown in **Figure 4.4**, and indicate the following:

- Most of the provinces in South Africa are predicted to experience an increase in the average annual precipitation as well as average monthly rainfall; and
- In Gauteng Province, an average ratio of increase between 1.2 and 1.4 is expected; i.e. the average annual rainfall is expected to be between 20% and 40% more than the rainfall in 2010.

The following observations are made:

- In view of the above, the volume of ingress may increase with the increase in annual rainfall in basins that are sensitive to rainfall-runoff patterns such as the Western and Eastern basins. This is mainly due to the seasonality of the river systems in these basins compared to the perennial rivers in the Central Basin attributed to leaking pipes and sewerage discharges; and
- Given that the actual volumes of ingress, effectiveness of measures to reduce ingress and average volumes to be pumped are all uncertain, no specific provisions have been made to mitigate the impact of climate change on this aspect of AMD.



Note: "Ratio" is defined as the expected change in annual rainfall in relation to actual annual rainfall during 2010 which was used as a bench mark for the study.

Figure 4.4: Average change in annual precipitation (Schulze, 2010)

4.3 Ingress Mechanisms

In order to try to minimise the amount of water entering the mine voids, it is important to identify the possible ingress mechanisms. This would aid in keeping the ingress as low as possible, as well as reducing long-term pumping, treatment and maintenance costs.

The main objectives of the ingress review are summarised as follows:

- Identify and source existing information on the ingress of surface water into the mine void;
- Review existing available information and extract main findings on the mechanism of ingress and possible mechanisms to reduce the surface water ingress;
- Determine the potential impact of the surface water ingress and source thereof on the decant volumes and water quality;

- Identify potential gaps in information and findings of the studies done to date;
- Give recommendations on possible additional studies/monitoring programmes required to improve the confidence of the predicted ingress volumes; and
- Give recommendations on priorities for and potential benefits of reducing ingress.

The following potential ingress sources and associated mechanisms were identified:

- Recharge through undisturbed geology;
- Ingress through shafts, inclines, adits and rehabilitated/backfilled opencast pits;
- Surface water resources (rivers, dams) seeping directly into mine openings and shallow groundwater systems above zones of historical surface operations and shallow undermining;
- Tailings dams and mine dumps serving as areas of enhanced and concentrated seepage where the volume of water entering the mine workings is usually found to be high; and
- Leaking sewerage lines and water mains, poor stormwater management and wastewater treatment.

4.4 Minimising Ingress

Natural recharge through the weathered aquifer is a diffuse process, and in general the management of this ingress will not be practicable. Care should however be taken to avoid the enhancement of the recharge of this aquifer through proper stormwater management in urban areas and other measures to avoid ponding of water on the surface. However, ingress could be reduced for the following ingress sources detailed below:

Mine residue deposits

In particular sand dumps and slimes dams have been identified as sources of ingress, particularly where these overly areas of shallow undermining or backfilled surface operations. These impacts can be addressed by capping dumps to prevent the infiltration of water and shaping the dumps to allow water to run off, rather than infiltrate. Ideally capping should be done with impermeable material, but even soil cover has been shown to significantly reduce infiltration (WUC, 2009).

Another method to reduce these impacts is removal of dumps and reworking to extract residual gold and uranium and final disposal on a properly engineered site. It is noted that the current method for re-working of the tailings dumps by hydraulic monitoring could also increase ingress into the mine void, due to the large water volumes utilised, but in the longer term, removal of these facilities will result in an overall improvement of the surface water and hence mine void water quality.

There are both positive and negative connotations to the reclamation of mine dumps (Liefferink, 2012), such as:

Positive

- Removal will partially remove one of the sources of water pollution and ingress;
- Removal will cause a reduction of wind-blown dust in the environment;
- Removal will expose the natural soil layer which the dumps were placed on, allowing vegetation growth and natural vegetation to re-establish after rehabilitation of the sites;
- Removal will liberate land for selected suitable redevelopment.

Negative

- Removal will exacerbate dust pollution until such time as protective vegetation cover is re-established or hardening of the exposed surface is achieved;
- A number of cases have been identified where the re-mining of dumps was not completed;
- Selective extraction of value from portions of a site;
- Radiometric surveys over previously reprocessed mine residue deposit footprints have, in some cases, shown elevated levels of residual radioactivity in the soils. In these cases, it must be accepted that some areas will never be suitable for unrestricted development and that these areas will need to be demarcated as such, and appropriate land uses proposed and implemented; and
- Re-mining of existing tailings dams introduces a new set of environmental risks. The associated contribution to contamination is likely to be considerable as old tailings are hydraulically mined using high-pressure water cannons. The reprocessing of tailings for the recovery of gold and uranium introduces large volumes of water and oxygen into anaerobic tailings which exacerbates pollution. It imposes a greater duty of care upon the operator to manage environmental impacts.

Although there are many risks associated with the removal of mine residue deposits, there are significant long-term benefits provided that the footprint of the dump can be adequately rehabilitated and remediated.

Rehabilitated/backfilled pits

The pits that have already been rehabilitated usually act as a “sink” to surface water ingress due to increased permeability of the backfill materials in the pit. It is therefore suggested that for these areas additional layers of backfill are placed over the pit area, compacted and shaped such that stormwater runoff is diverted and drained away from the pit. In addition, an impermeable clay layer should be placed over the backfill to reduce the infiltration potential.

Existing open pits

Where mined-out reef outcrops are close to or crossed by watercourses and runoff areas, they should be covered with an impermeable layer where practically possible. Shaping of this area should also be done so as to minimise the surface runoff from entering the reef area.

Existing open pits should be backfilled with suitable materials, such that the pit no longer accumulates surface water. The final layer of the backfill should again be a clay layer to minimise the infiltration potential.

Rivers, water bodies and stormwater drainage systems

Where a river crosses a shallow mined out area or a potential water bearing structure such as a major fault or dyke with suspected or proven hydraulic connection to the mine voids, possible canalisation and/or diversion should be considered. At water bodies such as dams and vlei areas, it will not be easy to implement control measures as this is primarily a diffuse source. This is sometimes impractical and requires more detailed and site specific studies. Further investigations that could be considered are:

- Identification and upgrade of stormwater where diverted into abandoned surface workings;
- Identification and prevention of the flow of stormwater into open pits;
- Audit of possible ingress via leakage from stormwater and main water supply systems; and
- Upgrading of stormwater management to prevent ponding, encourage runoff and ensure that stormwater is discharged to streams away from possible mine void ingress areas.

It should be noted that before any of the above control measures are implemented, further detailed and site specific cost-benefit studies would need to be undertaken. This would assist in determining the net benefit of implementing the control measures in relation to initial capital expenditure and a reduction in long-term operating and maintenance cost of pumping, water treatment and waste material handling.

The IMC (2010) report provides an action plan for short-, medium- and long-term interventions for the management of AMD. Although it does not provide any detail with regards to ingress prevention, it does state that for the short-term, prevention of ingress should be implemented immediately (or be continued in areas where already occurring). These short-term measures are discussed in more detail for each basin as they also form part of the long-term solution.

Specific Proposals

A summary of specific proposals which are captured in various reports is given in **Appendix C**.

The Council for Geoscience (CGS) is currently conducting a study which has ingress control as a component.

5 BACKGROUND INFORMATION

5.1 AMD Generation

It is generally accepted that the ultimate source of the AMD in the Witwatersrand gold mines is the pyrite (ca. 3%) contained in the auriferous conglomerates that are being mined. On exposure during the mining process, and with the addition of water and oxygen, the pyrite oxidises to sulphuric acid and iron. This is a complex process, but is generally simplified to the following reactions (Stumm and Morgan, 1996):

(1) Oxidation of pyrite and solubilisation of ferrous Fe

$$2FeS_2(s) + 7O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4SO_4^{2-}(aq) + 4H^+(aq)$$

(2) Oxidation of ferrous to ferric Fe

$$4Fe^{2+}(aq) + O_2(g) + 4H^+(aq) \rightarrow 4Fe^{3+}(aq) + 2H_2O(l)$$

(3) Direct oxidation of pyrite by ferric Fe (pH<3)

$$FeS_2(s) + 14Fe^{3+}(aq) + 8H_2O(l) \rightarrow 15Fe^{2+}(aq) + 2SO_4^{2-}(aq) + 16H^+(aq)$$

(4) Precipitation of ferric hydroxide (“yellow boy”) (pH>3)

$$Fe^{3+}(aq) + 3H_2O(l) \rightarrow Fe(OH)_3(s) + 3H^+$$

Although reactions 1 and 2 can take place spontaneously, they are typically slow and rate-determining. In nature, microbial catalysation of these two reactions by archaea and bacteria (e.g. acidophyllic *Thiobacillus ferrooxidans*) is well documented (Rawlings and Kusano, 1994; Trudinger, 1971). However, the end-product of these oxidation reactions is invariably a corrosive and potentially toxic AMD of variable quality (acidity and dissolved solids), depending on the ratio of pyrite to water quantity that was involved.

Dissolved sulphate forms the main salt component present in AMD of the Witwatersrand, making as much as 60% to 80% of the total dissolved solids (TDS), and presents the main challenge in treatment of the acid mine water. In addition, the Witwatersrand AMD may be enriched in heavy metals, including variable trace quantities of uranium, that derive from the metal sulphides, metal oxides and silicate minerals present in the auriferous conglomerate reefs.

It is conceivable that poor quality AMD can be either prevented, or ameliorated (i.e. returned to potable water quality) by dilution or chemical treatment (**Figure 5.1**). Since the prevention option is unlikely to be practically achievable, the other two options almost invariably need to be considered. Dilution is an attractive choice but may require large quantities of fresh water to blend with the AMD (blue arrows, **Figure 5.1**). For typical Witwatersrand AMD (TDS ~4 000 mg/ℓ), the dilution ratio needed is one part AMD with at least 10 parts fresh water. Among the chemical treatments, liming (green arrow, **Figure 5.1**) is one of the least costly options, causing a reduction of pH but only incomplete reduction in the salt concentration (Bowell, 2000). For more effective desalination, more aggressive (and expensive) sulphate removal treatments (black arrow, **Figure 5.1**) are clearly advisable. For the metal-rich Witwatersrand AMD, a biological sulphate reduction process which also removes heavy metals (Bowell, 2000), is considered optimal (**Figure 5.2**).

Mixing (blue arrows, **Figure 5.1**) is a two-way process. Either the AMD can be diluted to potable water, as suggested above, or potable water can be contaminated by AMD. The latter situation appears to occur in the vicinity of old mine dumps where surface runoff may enter open derelict mine shafts and workings and contaminate the mine void water. As a preventative measure, these dumps can either be moved or chemically isolated. Moving the dumps will reduce their negative impact at the site of removal, but will transfer the problem to the site of deposition. The costs involved in such massive earth moving operations are considered prohibitive given that they present an incomplete solution. Chemical isolation would probably also be costly due to the complexity of the task.

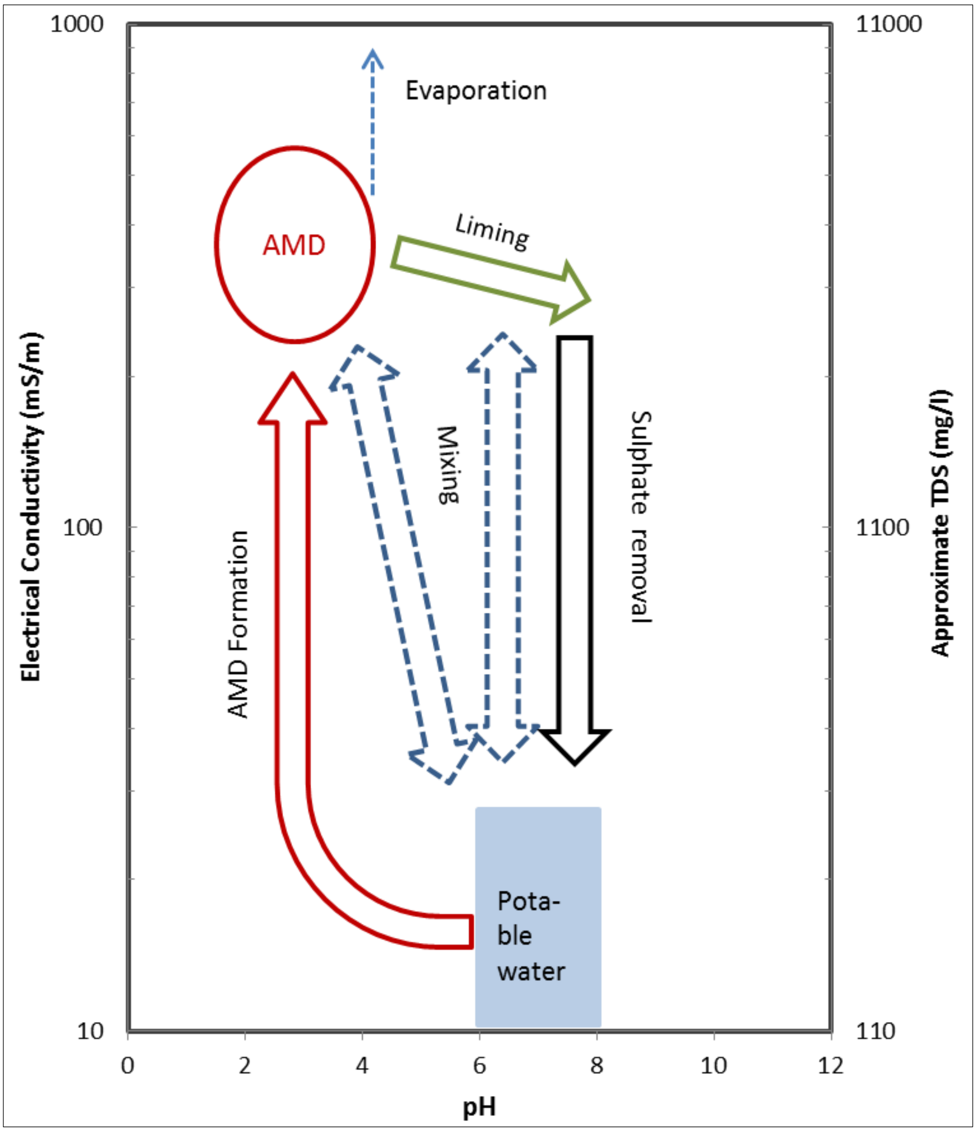


Figure 5.1: Schematic presentation of AMD formation and treatment

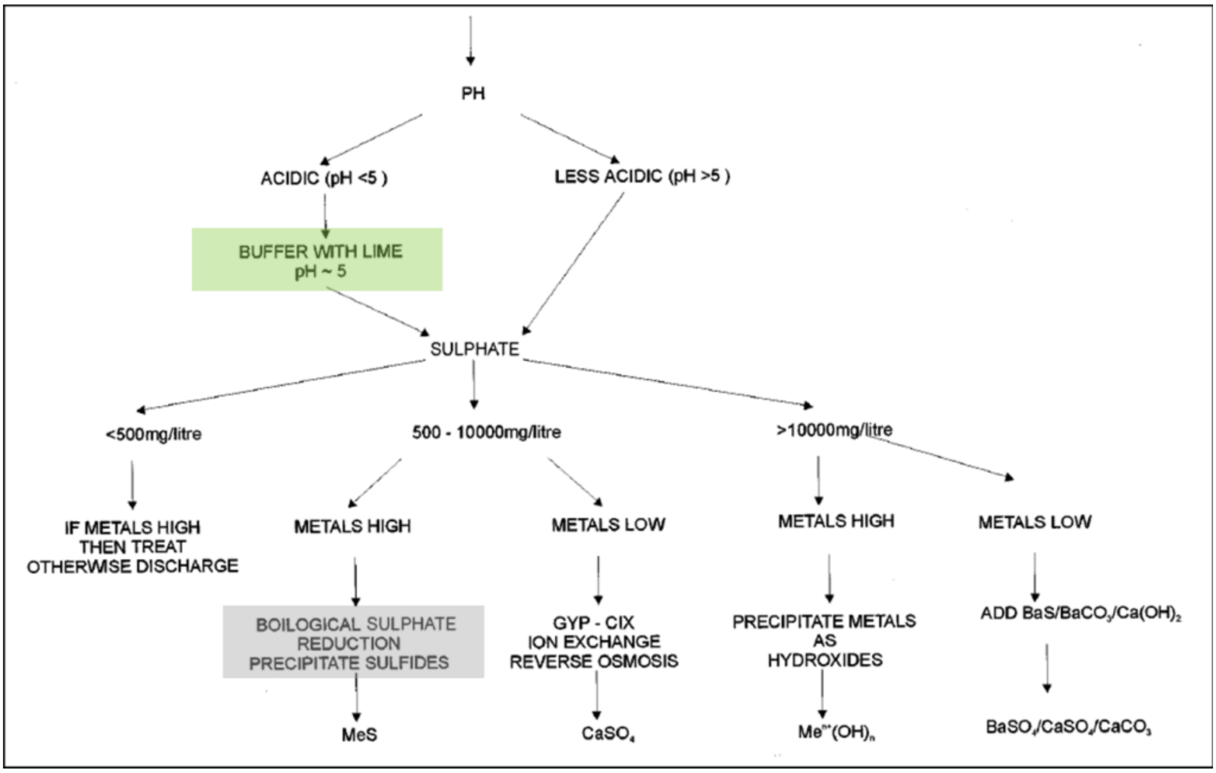


Figure 5.2: Treatment options of AMD after Bowell (2000)

The total salt in solution, expressed as total dissolved solids (TDS), is an important parameter in AMD in that it determines the quantity of sludge that will be generated on treatment. It is evident from the data sources consulted that TDS was seldom directly determined. In this report, the following estimates were used as appropriate where TDS was not directly determined:

- Summation of anion and cation concentrations for reasonably complete analyses;
- For incomplete analyses and SO_4 is available, TDS (mg/ℓ) ~ 1.5*SO_4(mg/ℓ); and
- Where SO_4 is not available but electrical conductivity (EC) was measured, TDS(mg/ℓ) ~ 11*EC(mS/m).

These equations are empirically determined and have been found to hold reasonably well for all three basins. It should also be noted that the TDS estimation using EC corresponds closely with the 10.6*EC (mS/m) equation used in the IMC (2010) report.

5.2 Data Considerations

In the interpretation of the chemical data presented in this report, it has to be considered that the data comes from a variety of sources and, as such, could be expected to be variable in purpose and quality. The following should hold true:

$$\text{Variance } V^{total} = V^{analytical} + V^{inherent} + V^{sampling}$$

$V^{analytical}$ derives from the between and in-laboratory differences in accuracy and precision. These differences are expected to be small relative to the other sources of variance.

$V^{inherent}$ includes a host of factors that affect the ultimate quality of the AMD, including, initial water-pyrite-oxygen ratio, degree of solids precipitation (e.g. ferric iron and other salts) effected by exposure to the atmosphere, degree of neutralisation/contamination due to wall rock reaction, activity of sulphate-reducing microbes, degree of dilution with fresh water ingress from surface or from groundwater sources, extent of isolation in shaft linings, human intervention, etc. By way of example, some highly contaminated AMD water has been recorded from surface ponds in the East Rand Proprietary Mines (ERPM) area, Central Basin (EC >1000 mS/m, **Figure 10.1**). These are most likely, in part, due to a proximity to mine dumps, and, in part, a response to evaporation. It is also known that in both the Western and Eastern basins, the observed AMD quality improved notably with time (**Sections 6.7.3** and **8.7.3**). In both instances, wall rock reaction and, possibly, some dilution with fresh water may have contributed to the overall effect. Also, the water sampled in the shafts in the Central Basin clearly shows dilution due to surface ingress (**Table 7.10**, comparison between shaft and underground water; **Figure 10.1**). Some degree of reaction with shaft linings is suspected in the water samples from the Central Basin.

In view of the possible inherent variations in AMD quality, $V^{sampling}$ expectedly represents a major source of variance, dominant among which probably are locality of sampling and sampling date relative to closure of mine. It should be obvious that AMD ponded on surface and exposed to evaporation will tend to increase the salt load to a point of saturation and precipitation of solids (e.g. gypsum), whereas water in the mine void, continuously mixing with either surface of underground water ingress, will tend to be diluted.

The planned pumping exercise may be essentially considered as a continuous sampling procedure and as such, depending on location and rate of abstraction relative to connectivity of the mine void in the direct vicinity of the pump station, may draw from a diverse range of AMD qualities. However, with time, as the water flow to the pumps reaches a dynamic equilibrium, the AMD reporting to the pump stations should converge to a more constant quality. However, the nature of this quality will depend on local conditions and can only be predicted in very broad terms.

It should be also be noted that the uranium values reported here reflect those that were included in overall water chemistry analyses and should be considered as indicative values only. Radiogenic water data will be assessed and described separately in the water treatment component of the Feasibility Study.

5.3 HDS Composition

Whilst the treatment aspects of high density sludge (HDS) are addressed by other components in this Feasibility Study, the possibility of disposing of the sludge into the underground environment of the mine void has been ventured and is therefore discussed briefly in this report. The estimated bulk composition of HDS on the Witwatersrand is provided in **Table 5.1** for the water quality at the 75th percentile.

Table 5.1: Estimated HDS sludge composition

Precipitate [dry basis]	Units	Sludge Composition		
		Western Basin	Central Basin	Eastern Basin
$Fe(OH)_3$	%	32.5	31.6	38
$Fe(OH)_2$	%	1.4	3.7	2
$Al(OH)_3$	%	3.0	0.1	0
$Mn(OH)_2$	%	9.2	1.6	1
CaF_2	%	0.0	0.0	0
$Ca_3(PO_4)_2$	%	0.0	0.0	0
$Mg(OH)_2$	%	0.0	0.0	4
$CaCO_3$	%	4.9	4.4	1
$CaSO_4$	%	49.1	58.6	55
Total Sludge [dry]	tons/day	148.4	345.7	152.5
Total [if filter cake @ 65% solids]	tons/day	228.3	531.8	234.6
Total [if filter cake @ 65% solids]	m^3/day	142.7	332.4	146.6
Total [if sludge @ 10% solids]	tons/day	1 484.2	3 457.0	1 525.0
Total [if sludge @ 10% solids]	m^3/day	1 349.2	3 142.7	1 386.3

Source: DWA AMD FS 2012, Study Report No 5.4: Treatment Technology Options

The sludge consists primarily of gypsum and hydrated oxides of iron and manganese. It has relatively low carbonate content. Witwatersrand AMD also contains significant amounts of other metals which have not been listed in **Table 5.1**. Some indication of their abundance relative to iron is provided by the AMD seepage analyses shown in **Table 5.2**.

The majority of the metals listed in **Table 5.2** will precipitate along with iron and manganese in the liming process of the HDS plant. The sludge is therefore likely to contain significant quantities of cobalt, copper, nickel and chromium. It will probably also contain some uranium due to co-precipitation.

Table 5.2: Chemical composition of acid mine seeps in Germiston, Central Basin (Naicker *et al*., 2003)

Analytical results for ground and surface waters collected over 10 km reach of the Natalspruit[a]

Sample	pH	Eh mV	Cond mS/cm	SO_4^{2-} mg/l	Cl^- mg/l	Cr mg/l	Zn mg/l	Pb mg/l	Cu mg/l	Fe mg/l	Mn mg/l	Co mg/l	Ni mg/l	Na mg/l	Ca mg/l
1S	7.01	277	0.37	250	21.00	1.65	0.1	0.00	0.10	2.38	0.30	0.00	0.13	10.24	84.60
1G	7.04	157	0.81	300	12.00	2.01	5.0	0.10	0.20	9.78	0.40	0.00	0.10	19.07	125.20
2S	6.17	269	1.5	500	12.00	2.01	1.5	0.10	0.10	26.61	6.20	0.69	1.02	49.26	125.80
3S	7.90	277	0.5	360	17.40	2.01	0.0	0.10	0.10	0.62	0.00	0.00	0.10	18.06	69.40
4E	3.08	600	5.71	2080	80.00	5.90	8.0	0.40	6.00	384.30	86.60	14.30	17.88	25.64	133.10
4S-A	5.78	316	1.31	680	17.50	2.19	1.0	0.10	0.10	19.19	8.30	0.37	1.06	38.99	121.00
4S-B	5.49	375	1.37	570	17.40	2.19	1.1	0.10	0.10	23.82	8.00	3.10	1.26	24.36	141.60
4S-C	5.25	400	1.38	530	18.06	1.65	1.2	0.10	0.20	24.84	8.50	0.62	1.38	46.81	145.20
4G-A	3.76	432	5.45	1750	36.40	9.97	8.0	0.70	6.00	453.40	68.00	11.40	15.28	22.60	125.70
4G-B	3.78	431	4.77	1400	26.70	5.82	7.0	0.30	5.00	379.00	72.00	10.30	15.38	23.28	116.40
5S	7.14	158	0.94	430	17.40	2.01	0.1	0.10	0.10	12.09	1.40	0.00	0.35	36.05	127.30
5G	4.56	408	1.33	570	23.50	2.01	1.4	0.20	0.40	3.69	2.40	0.00	0.57	29.09	204.10
6S	6.73	201	0.85	370	18.20	2.01	0.3	0.20	0.20	10.09	0.60	0.00	0.43	44.95	117.30
6G	3.96	394	5.7												
7S	4.49	442	1.14	530	16.00	2.01	1.5	0.20	0.30	77.60	2.00	0.00	1.27	29.31	100.90
8S	6.36	236	1.2	500	12.00	2.01	0.5	0.20	0.20	17.38	2.80	0.00	0.64	44.55	122.90
9S	6.14	291	1.04	430	10.80	2.01	0.4	0.10	0.10	14.70	2.50	0.00	0.59	35.40	127.10
10S	6.53	234	1.01	490	12.00	2.01	0.4	0.10	0.20	13.06	2.10	0.00	0.55	40.55	115.30

S, surface water, G, ground water; E, seepage water.

[a] Samples were collected in October 1999.

Under elevated pH conditions (the pH of HDS is estimated to range from 8 to 10), most of these metals will remain in the solid form as hydrated oxides. However, should the sludge be transferred into the subsurface environment, which is inherently acidic due to sulphide oxidation, the carbonate will dissolve and once that is consumed, the metal oxides will also dissolve into the void water. Unless the voids where the sludge is deposited can be isolated, this will probably result in continual recycling of the more serious pollutants particularly if the sludge is not disposed of at considerable depth. The anticipated improvement in the quality of water being pumped from underground could be seriously delayed if not compromised.

The current volume of the mine void at depth (say >1 000 m) is unknown, but it is postulated (Winde *et al*., 2011) that the stopes will have closed. The remaining void will be haulages and cross cuts, etc., which generally slope towards the shafts. It is therefore not considered prudent to contemplate disposing of the HDS into the mine void without a specialist feasibility study into all the implications. This study would also have to investigate the status and accessibility of shafts into potential compartments. The alternative of establishing very deep boreholes should be considered, but will have a high capital cost.

Ideally, the sludge should be converted into a saleable form. If the iron could be separated from the gypsum, it could possibly be used as a pigment in paint or even sold to scrap metal recyclers. Every effort should be made to achieve this goal. In the interim, co-disposal with tailings is the preferred option.

6 WESTERN BASIN

6.1 Geological Setting

The Witwatersrand Supergroup strata in the Western Basin have been folded into an open, basin-like syncline which plunges towards the south-east (**Figure 6.1**). The dips of the Central Rand Group strata vary from about 20° to as much as 70° to the south, south-east and east in this syncline. The syncline terminates against an up-faulted block known as the Witpoortjie Gap or Horst, which is bounded by the Witpoortjie Fault in the north and Roodepoort Fault in the south.

The Witwatersrand strata in the Western Basin are partially buried beneath younger Transvaal Supergroup strata, specifically the Black Reef Formation and overlying dolomite (**Figure 6.1**). Unlike the Witwatersrand strata which are strongly folded, the rocks of the Transvaal Supergroup have experienced only very gentle warping and are tilted only a few degrees from the horizontal to form shallow troughs and swells. Some of these rises and depressions may even reflect the original topography of the surface on which the Black Reef Formation was deposited.

The dolomite that overlies the Black Reef Formation in the syncline (**Figure 6.1**) is generally thin and largely decomposed to form a very porous, iron-manganese oxide mixture known as wad. Only isolated remnants of the original dolomite remain. Further to the north-west the dolomite is more extensively developed and hosts the famous Cradle of Humankind World Heritage Site.

The lower West Rand Group strata contained little gold, but in the upper Central Rand Group, many of the conglomerate beds contained economic gold and as many as 22 reefs were mined to varying extents. The up-faulted Witpoortjie Horst consists of West Rand Group strata and was thus not mined. The reefs in the West Rand syncline were followed down from surface to a maximum depth of around 1.5 km where they terminate against the Witpoortjie Fault (**Figure 6.1**). The conglomerate layer in the Black Reef Formation is sporadically mineralised and was mined using both opencast and underground mining methods.

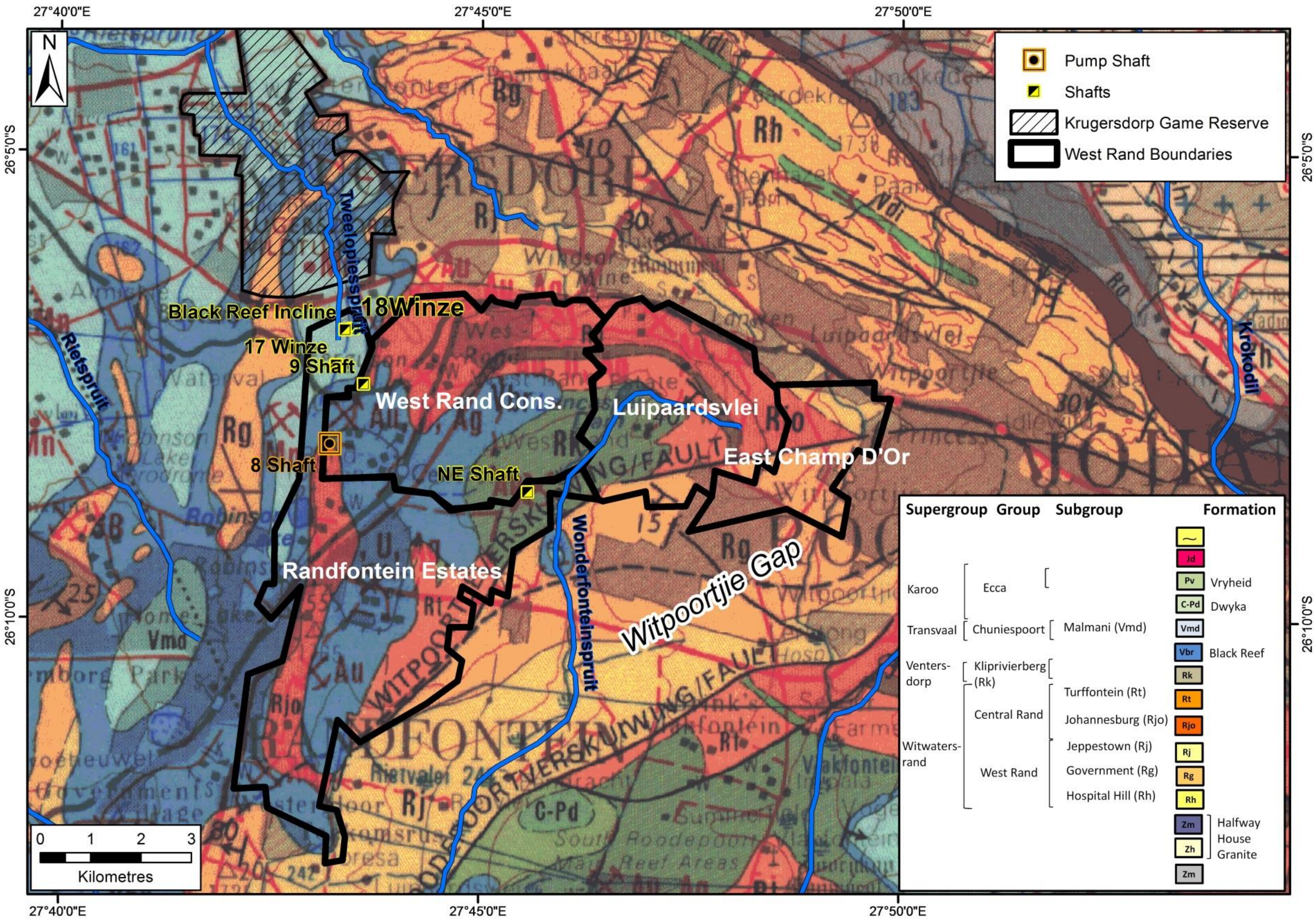


Figure 6.1: Geological map of the Western Basin, showing mine boundaries and selected shaft positions

6.2 Hydrogeological Setting

Figure 6.2 shows the conceptual hydrogeological model for the Western Basin in a cross-section from north-west to south-east. Groundwater occurs in the weathered and fractured sedimentary rocks of the Witwatersrand rocks. These shallow water-bearing horizons are not considered to contain economic and sustainable aquifers but localised high yielding boreholes exist where significant fractures, seldom deeper than 60 m below surface, are intersected. The hydraulic conductivity and storativity of the weathered aquifer is generally low and groundwater movement through this aquifer is therefore slow.

The dolomite outlier within the syncline (**Figure 6.1**) represents the most prominent aquifer in close proximity to the Millsite tailings facility and the Western Basin mine voids, and is consequently the most vulnerable to groundwater contamination. The dolomite aquifer in the Western Basin is separated from the Zwartkrans Compartment dolomite aquifer which lies to the north-west of the syncline, by Witwatersrand quartzite. There is some speculation that groundwater flow through the fractured Witwatersrand rocks could allow for some interaction between the compartments but this is unproven. The Zwartkrans Compartment is more likely to be impacted by surface water contamination from the Tweelopies Spruit, into which surface decant from the mine void is currently occurring (Hobbs and Cobbing, 2007 and Hobbs, 2011).

The Zuurbekom Compartment dolomite aquifer is located to the south of the Witpoortjie Horst and is unlikely to have a direct interaction with the West Rand Basin. However, this dolomite aquifer, which extends along the entire length of the Western and Central basins, has been severely polluted by discharge from the tailings dumps (Kafri and Foster, 1989).

Since complete flooding of the Western Basin mine void in 2002, the water table is close to surface and the hydraulic gradient has been reversed such that groundwater flow is from the mine void via shafts and boreholes, breaching the hydraulic divide and decanting into the Tweelopies Spruit and ultimately into the Limpopo River Catchment,

By lowering the water table in the mine void, the hydraulic gradient will be towards the mine void and uncontrolled decant will be stopped.

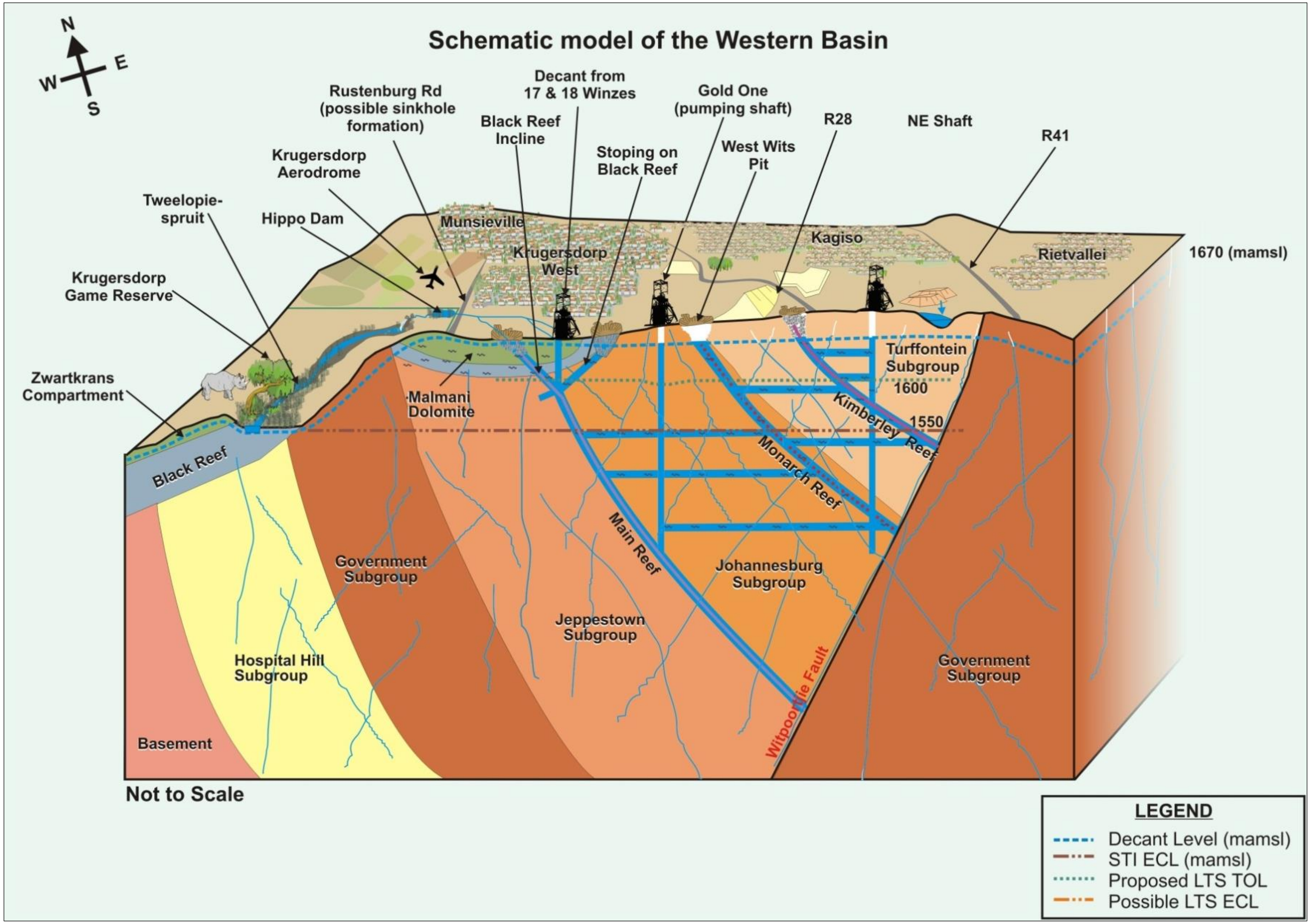


Figure 6.2: Schematic illustration of a conceptual hydrogeological model for the Western Basin

6.3 Mine Voids

6.3.1 History, distribution and connectivity

The Western Basin consists of four mines: Randfontein Estates, West Rand Consolidated, East Champ d'Or and Luipaardsvlei (**Figure 6.3**). As such, it is distinct from the West Rand Goldfield that, in addition to these mines, also includes the Doornkop, Cooke Section, Ezulwini and South Deep mines to the south of the Western Basin.

The major mined out area is shown in **Figure 6.3**, which illustrates the huge extent of the mine void. In the last few decades, the shallower, lower grade reefs have been mined by opencast methods. The mine void of the Western Basin is separated from the Central Basin by the Witpoortjie Gap, a horst block bounded by the Witpoortjie Fault in the north and Roodepoort Fault in the south. No Central Rand Group strata are preserved in the Witpoortjie Gap and consequently no mining took place in this area. The southern mines of the West Rand Goldfield are also not connected to the Western Basin mine void because of the Witpoortjie Gap.

A thorough evaluation of the interconnectivity of the Western Basin mine void is prohibited by the long mining history, from the late 19th Century onwards. A large number of reefs have been exploited, potentially leaving smaller, isolated mine voids that are not interconnected, such as in the Randfontein Estates area (number 1 in **Appendix B**), where underground mining of the Black Reef took place.

However, the available evidence supports a high degree of interconnectivity and reasonably free flow within the main void in the basin.

Water is considered to enter the mine void in a variety of ways.

- Rainfall and local runoff enters the void directly along the disturbed zone that follows the outcrops of the numerous mined reefs. For example, extensive opencast mining of the flat-lying Black Reef Formation conglomerate has taken place in the area (notably by Lindum Reefs). These workings were often backfilled with overburden. Also, the so-called Black Reef workings occasionally intersected the underlying mining void of the Witwatersrand reefs. The combined effect of these mining practices has probably hugely increased the area of disturbed zone above the mine void, thus increasing recharge into the deeper void.
- Groundwater from the shallow weathered aquifer, where it is undisturbed by mining, flows laterally into the disturbed zone and enters the void.
- At depth, depressurisation caused by the mine void will lead to groundwater flow into the void via permeable structures.

6.3.2 Water levels

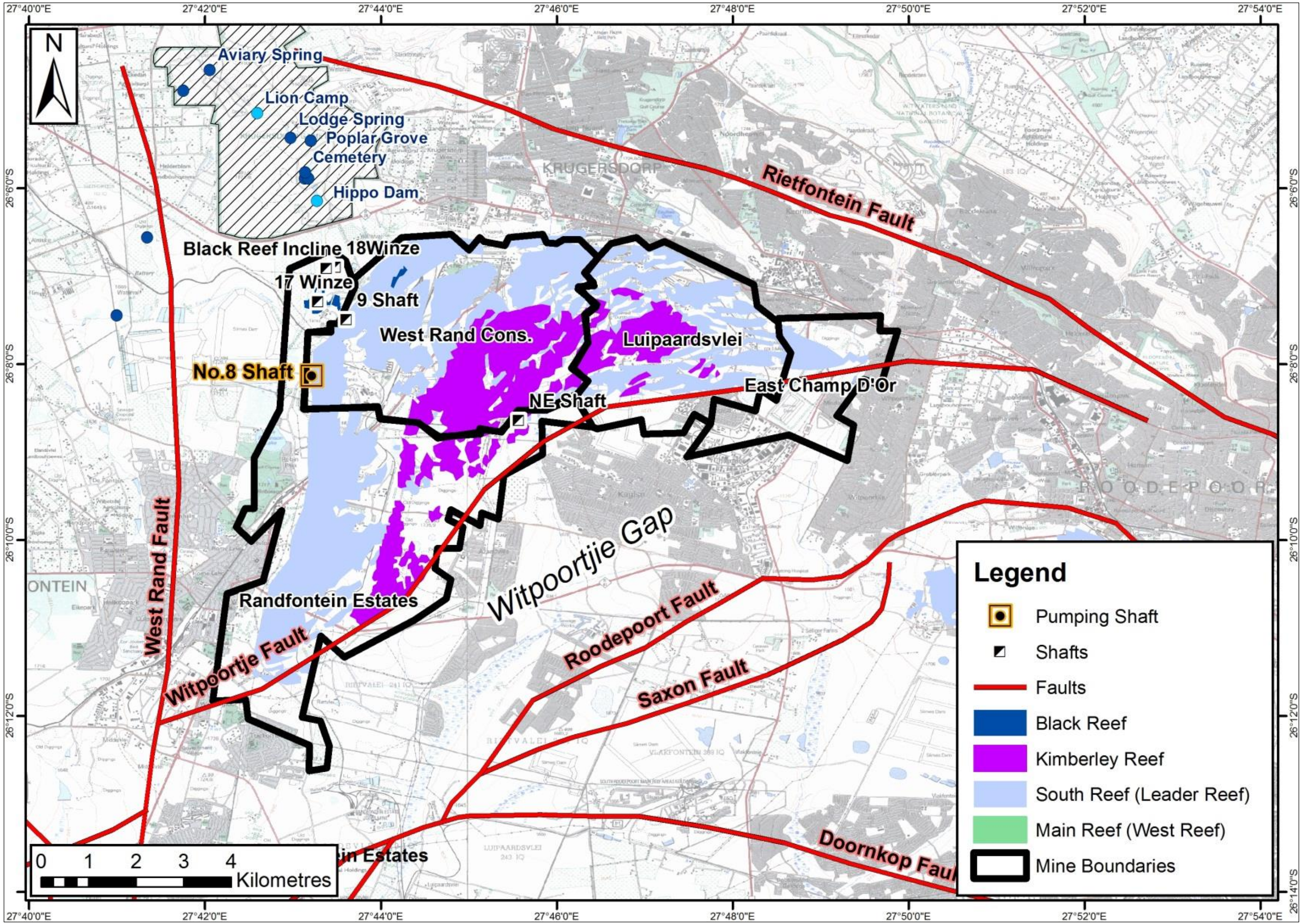
Following cessation of mining in the area in 1998, the mine void in the Western Basin filled with water and finally began to decant on surface in 2002. Surface decanting takes place through three old shafts, the Black Reef Incline (BRI) (1 669 m amsl) and No.'s 17 (1 679 m amsl) and 18 Winzes (1 677 m amsl).

The No.'s 17 and 18 Winzes (a winze is a shaft sunk at an angle so as to lie on the reef plane) seem to have accessed the West (Main) Reef conglomerate beneath the Transvaal Supergroup strata (**Figure 6.1** and **Figure 6.4**). Once the West Reef void had filled, mine water probably decanted underground into the Black Reef workings (**Figure 6.4**) and from there seeped into the shallow dolomite trough lying west of the Main Reef sub-crop. Other Witwatersrand reefs may also be connected to the Black Reef workings, however the West Reef is the most significant from an underground decant perspective. The very first surface decant took place from a water borehole (CPS) situated alongside the Tweelopies Spruit, just below the position of the BRI portal. This was followed by decant from the BRI and finally the two Winze Shafts as the water level in the void continued to rise. This finally resulted in a rise in the water table in the karst outlier that hosts the locus of decant and the Hippo Dam downstream in the Krugersdorp Game Reserve filled with water (H Coetzee, personal communication, 2011).

The water discharging from the mine workings is acidic and contains elevated concentrations of iron, manganese and other metals. Upon exposure to air, the dissolved iron undergoes oxidation, further lowering the pH. The iron, manganese and other metals then precipitates as unsightly yellow to orange or black oxide sludge along the bed of the Tweelopies Spruit. Where the river cascades over falls or rapids, thick crusts of iron and manganese oxides have formed. Over the years since surface decant commenced, the extent of this iron precipitate has extended progressively further downstream. The water is toxic and has a profound impact on aquatic biodiversity.

The geological relationships along the course of the Tweelopies Spruit and in the vicinity of the surface decant points are of some interest and are illustrated in **Figure 6.5**. The elevation of the water level in the void is shown by water level measurements in the Central Vent Shaft (see **Appendix A** for locality) and CPS borehole (in close proximity to and just below the BRI) to be at 1 671 m amsl. The cross-section illustrates the direct connection between the Black Reef workings and overlying dolomite and the sub-cropping West (Main) Reef void (see also **Figure 6.4**, which suggests that the stoping on the West Reef intersected that on the Black Reef). This connection only exists at elevations close to the sub-crop of the West Reef against the Black Reef. At lower elevations, the West Reef void diverges from the Black Reef as the former dips to the southeast and the latter to the west (**Figure 6.5**). The section moreover shows that the dolomite-bearing trough (outlier) in the vicinity of the surface decant points is isolated from the main dolomite to the north by West Rand Group strata of the Witwatersrand Supergroup (also noted by Hobbs and Cobbing, 2007).

There has been a suggestion that contaminated water may be seeping from the dolomite outlier through fractures in the West Rand Group quartzites to emerge in springs below the lodge in the Krugersdorp Game Reserve. This possibility cannot be verified on the basis of currently available information, but is considered to be unlikely. The contaminated springs in the reserve are more likely to arise from infiltration of contaminated surface water into the dolomite north of the lodge (e.g. Hobbs, 2011).



Note: Decanting shafts (17 and 18 Winzes and Black Reef Incline) are annotated, as are significant springs and dams on the Tweelopies Spruit. Note that the reef voids are projected to surface, therefore upper reef voids will obscure lower reef voids in some areas.

Figure 6.3: Mine voids of the Western Basin

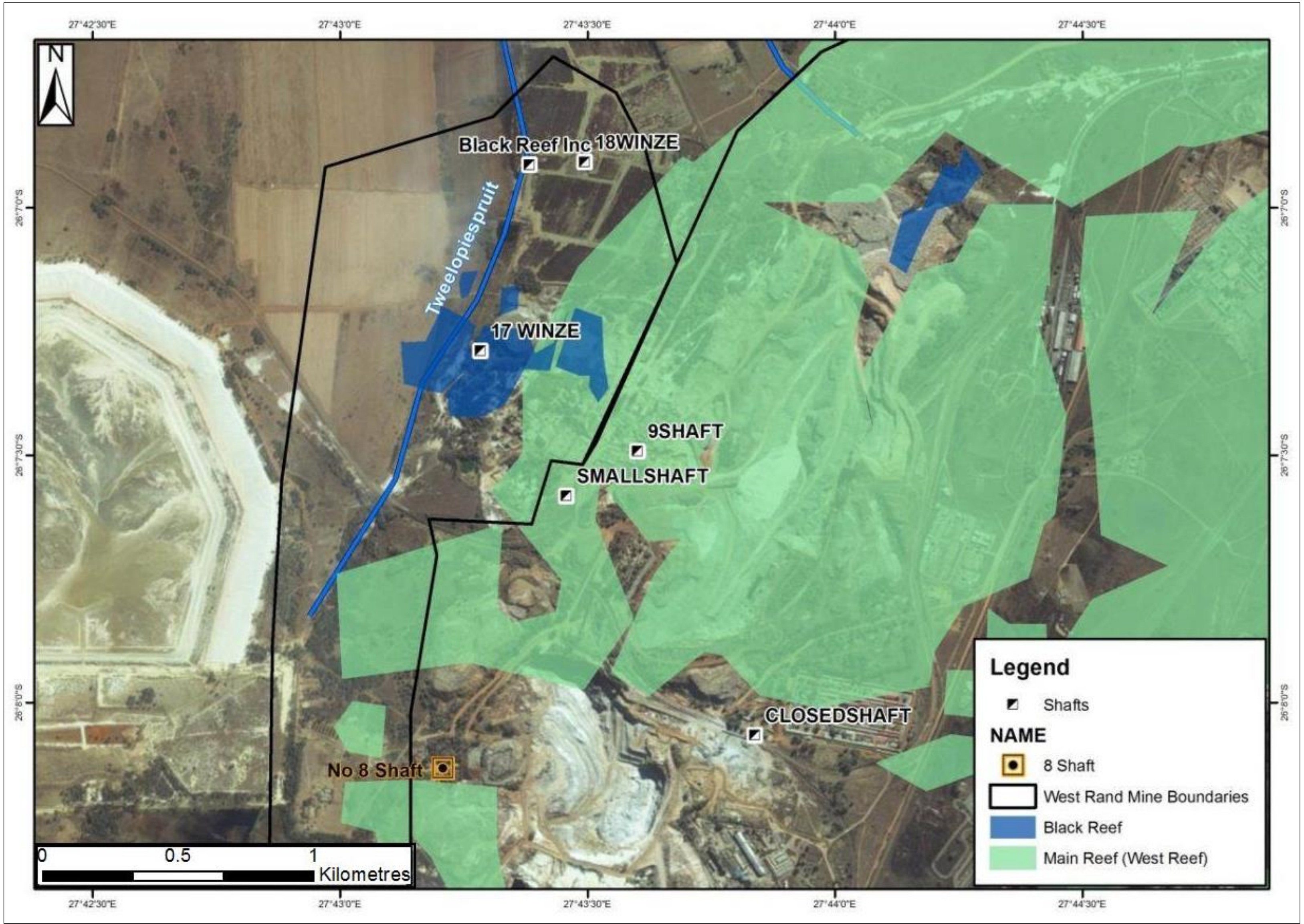
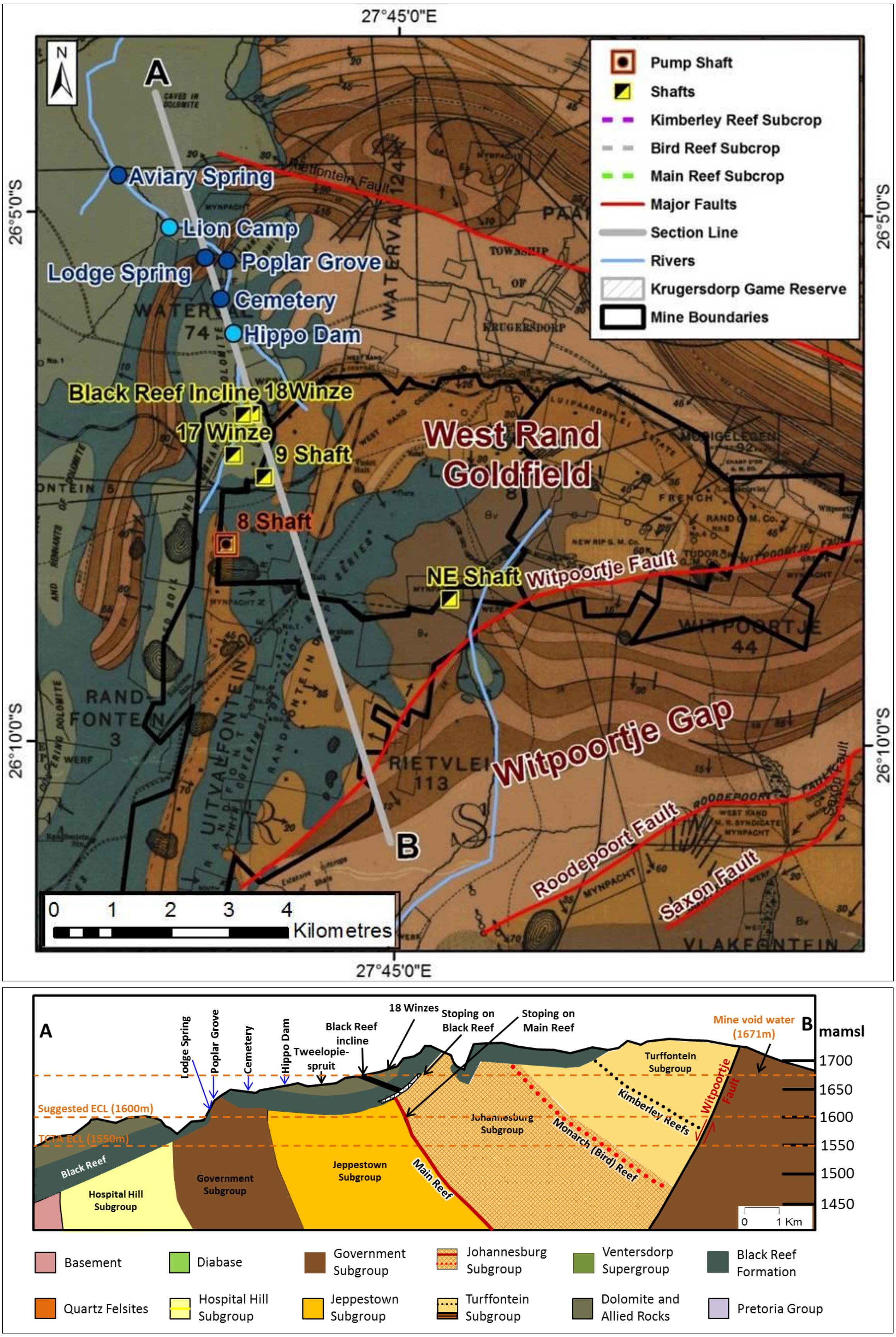


Figure 6.4: Map of stoped areas on the Black Reef and West Reef, showing overlap in the vicinity of 17 Winze

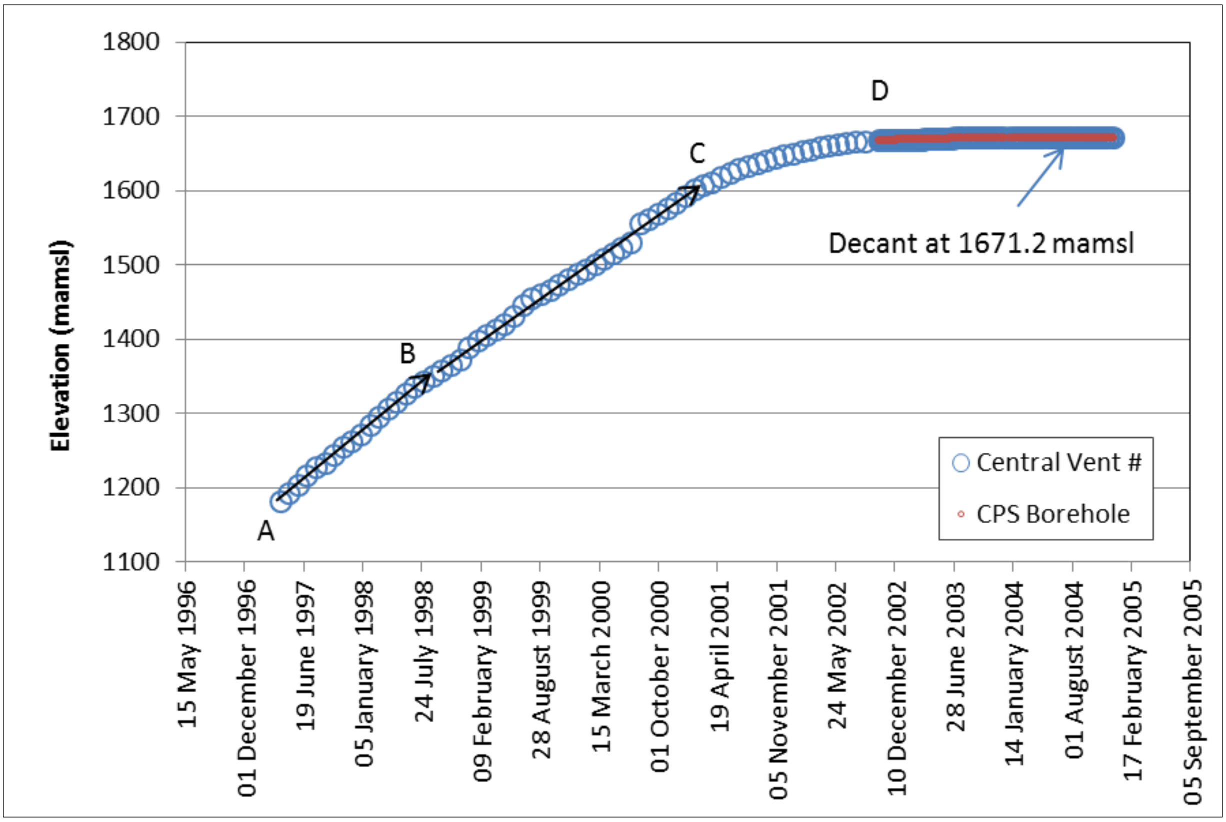


Note: Cross-section shows the current surface decant water level, ECL as defined in the TCTA (2011) report, and the ECL as proposed in this report. Hatched area in cross-section, from the Main Reef to the Witpoortje Fault, denotes area of historic mining activities.

Figure 6.5: Geological map of the West Rand Syncline, with a cross-section along the fold axis

Available data on historic water levels and connectivity between mines is limited. However, the large number of reefs mined in the Western Basin, combined with the large number of shafts (**Figure 6.3**), suggests that the mine voids in the entire Western Basin are well connected. **Figure 6.6**, based on data received from the CGS and Rand Uranium, shows the rising water level leading up to surface decant. The BRI decant level (1 669 m amsl, Google Earth) is within 2 m of the decant level measured in the mine at Central Vent Shaft.

Two slope changes marked as B and C on the filling curve (**Figure 6.6**) suggest major events pertaining to the filling of the Western Basin. The prominent apparent off-set on the filling curve between March and October 2000 remains unexplained, and could possibly be an artefact.



Note: A, B, C and D mark events in the void filling process

Figure 6.6: Water level rise in the Western basin prior to surface decant in 2002

6.4 Critical Water Levels

The ECL for the Western Basin (**Figure 6.5** and **Figure 6.7**) has been proposed at an elevation of 1 550 m amsl in the TCTA (2011) report (**Table 2.3**). It should be noted that this is proposed as a Target Operating Level (TOL) and allows for some fluctuation and higher water levels to occur from time to time. This elevation was chosen to protect the Zwartkrans Compartment karst aquifer from possible ingress of raw mine water via seepage through fractures connected to the void (Hobbs and Cobbing, 2007).

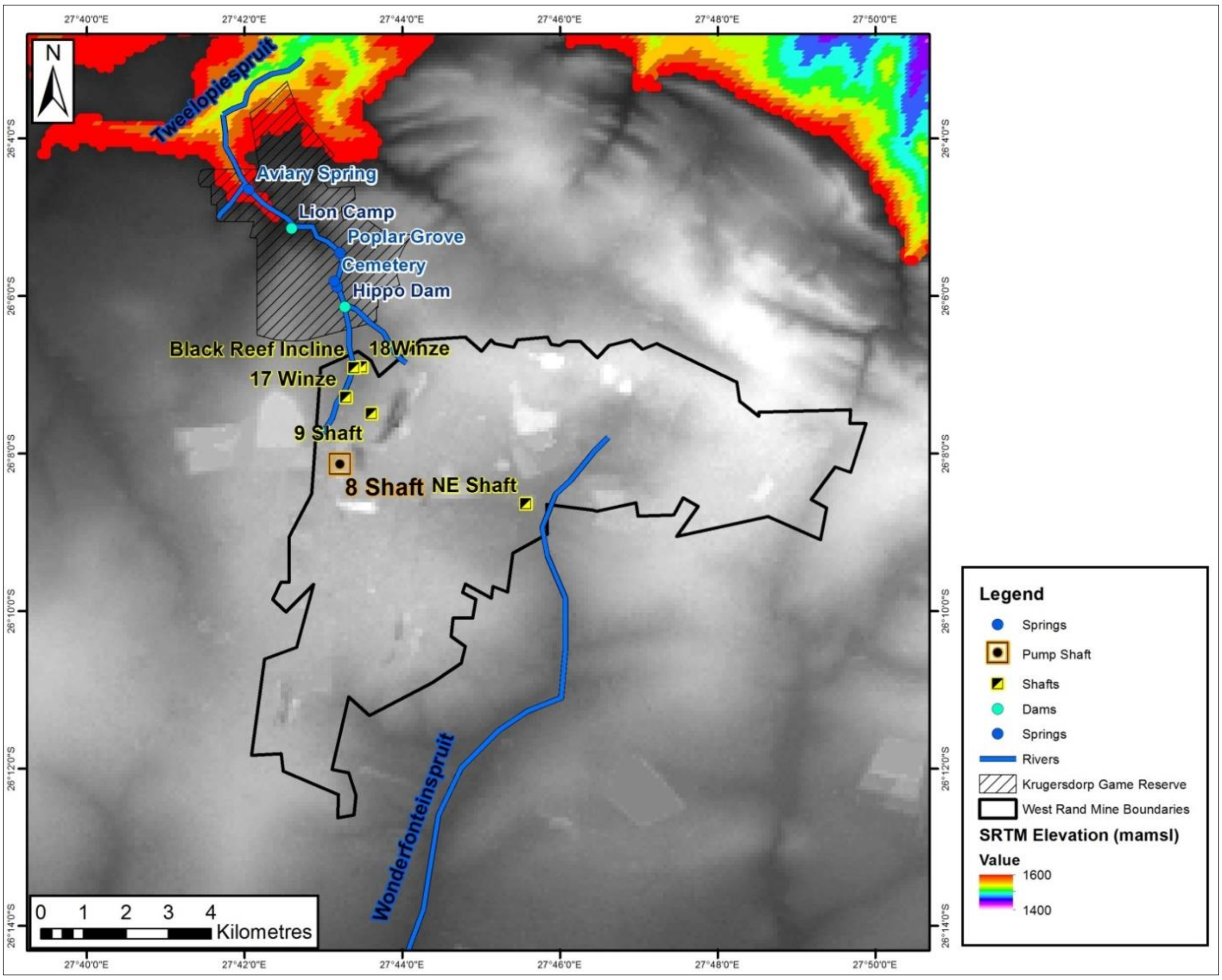


Figure 6.7: Elevations in the West Rand below 1 550 m amsl defined by Shuttle Radar Topography Mission (SRTM) data.

6.4.1 Proposed Environmental Critical Level

A key consideration for the definition of an ECL for the Western Basin is the preference to contain the mine void water within the quartzitic rocks of the Witwatersrand Supergroup and away from the dolomite aquifer.

It is evident from **Figure 6.5** that ingress into the Black Reef and its thin overlying veneer of dolomite probably occurs via the sub-crop of West Reef against Black Reef. Supporting information sets this intersection at approximately 1 610 m amsl, as indicated in **Figure 6.6** (point C). If the water level in the void were to be lowered substantially, this connection would be broken and the void would then be separated from the dolomite by a thick sequence of shale and quartzite of the West Rand Group (mainly Jeppestown Subgroup). Accordingly, it is suggested that a static water level at 1 550 m amsl may be unnecessarily conservative and a level just below the 1 610 m amsl level at which mine water appears to have entered the dolomite aquifer via the Black Reef workings, should be targeted.

An ECL of 1 600 m amsl is thus proposed, as it is considered that this will sever the Witwatersrand/Black Reef mine void connection and provide sufficient protection of the dolomitic aquifer to the north from direct inflow of void water (**Figure 6.8**).

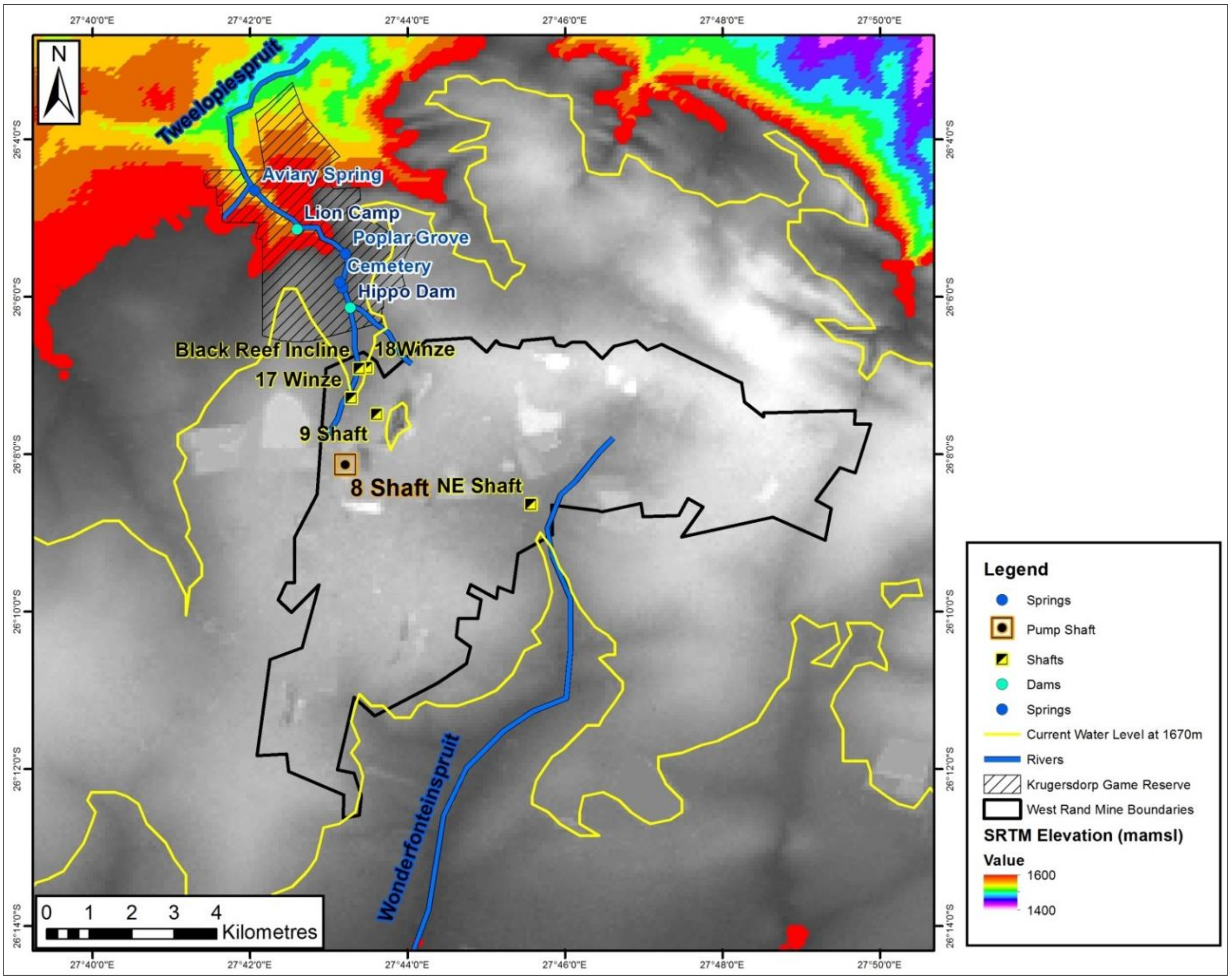


Figure 6.8: Elevations in the Western Basin below 1 600 m amsl defined by Shuttle Radar Topography Mission (SRTM) data.

To assess the results of dewatering and reduce the associated risks, the mine water level should be lowered to an ECL of 1 600 m amsl level and held there for an appropriate duration to establish whether the situation downstream improves. Careful monitoring of springs rising at and above 1 600 m amsl would therefore be required in order to assess the flow of water from the void into the groundwater. If leakage of AMD into the springs ceases then the water could be held at this level; if not it should be lowered further, i.e. towards the TCTA proposed level of 1 550 m amsl. However, it is important that sufficient freeboard is allowed to cater for pumping strategies, pump failure, maintenance, etc.

The void is not the only source of noxious water and this fact needs to be considered when monitoring the impact of lowering the mine water level on groundwater qualities. An additional contributor to groundwater pollution outside of the confines of the void derives from the large tailings dump located to the north-west of Randfontein Estates Gold Mine (REGM) (**Figure 6.9**). This source of AMD can only be addressed by removing the dump and remediating the area.

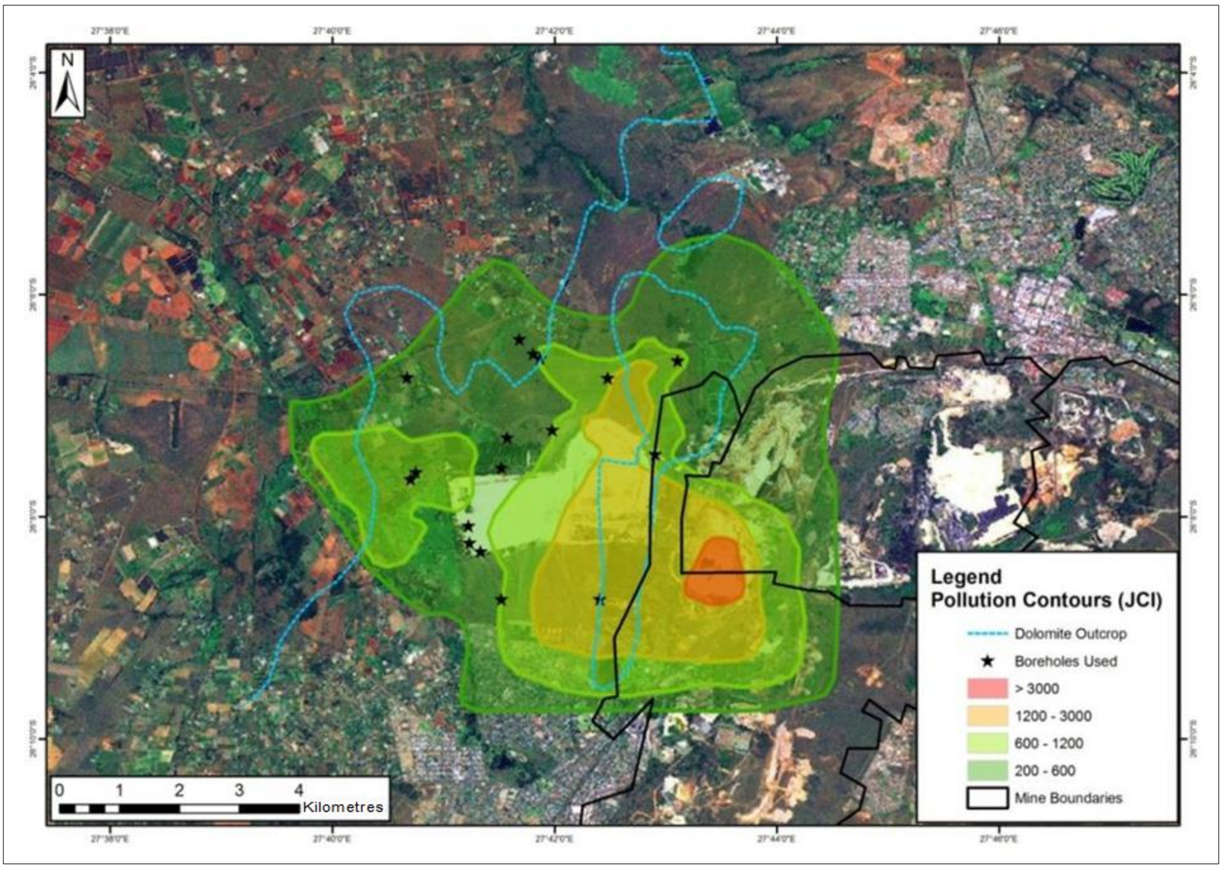


Figure 6.9: Pollution contours (mg SO_4/ℓ) over mine dumps in the Randfontein Estates area during the mid-1990s

6.5 Surface Water Ingress

The Western Basin is situated on a major water divide with the Wonderfontein Spruit (a tributary of the Mooi River) draining to the Vaal River in a south-westerly direction. The Tweelopies Spruit drains the remainder of the basin in a northerly direction and falls within the upper Crocodile River (West) Catchment, which flows into the Hartbeespoort Dam and ultimately the Limpopo River.

This area is characterised by undulating topography in the south but more hilly terrain along the northern boundary of the mining area.

For each of the ingress sources described in **Section 4.3**, a percentage of recharge (ingress) of the rainfall and surface water runoff was estimated taking into account the existing geological formations as well as potential ingress sources to predict the expected ingress volumes into the mine workings. In addition, relevant and applicable rainfall records were scrutinised before being able to determine the ingress volumes.

6.5.1 Meteorology

The major source of basin inflow is direct rainfall on open surface mine areas or surface runoff generated from rainfall falling onto a catchment area. A 60 year record (1949 to 2009) was used (WUC, 2009) as this was the most current record available at the time of the study.

The extracted monthly average rainfall is presented in **Table 6.1** and the annual minimum and maximum rainfall in **Table 6.2**.

Table 6.1: Average long-term monthly rainfall, Western Basin (WUC, 2009)

Month	Average Rainfall (mm)	Minimum Rainfall (mm)	Year Recorded	Maximum Rainfall (mm)	Year Recorded
October	68.85	9.9	1958	168.77	1993
November	101.89	25	2002	197.4	1949
December	107.25	47.5	1957	252.5	1949
January	132.03	60.4	1956	292.25	1977
February	98.78	34.4	1976	268.9	1955
March	91.19	9.75	1965	201	1997
April	50.7	0	1956 & 2002	109.35	1975
May	15.03	0	Often	68.55	1975
June	7.61	0	Often	49	1957
July	3.24	0	Often	65.2	1952
August	6.33	0	Often	38.37	1986
September	22.87	0	Often	123.97	1987
Total	**705.75**				

Table 6.2: Annual minimum and maximum rainfall, Western Basin (WUC, 2009)

Month	Driest Year - 2002 (mm)	Wettest Year - 1955 (mm)
October	67.35	54.65
November	25	137.45
December	114.45	154.35
January	94.25	268.3
February	58.5	268.9
March	38.15	54.25
April	0	60.55
May	4.5	45.25
June	9.25	3.6
July	0	0.25
August	5.5	3.4
September	0	1.3
Total	**416.95**	**1 052.25**

In addition to the above data, an independent validation of the rainfall record was completed for the Western Basin. The results are summarised in **Table 6.3** for the selected weather stations. Two stations were compared, namely 0475370W and 047456W both with 86 years of record (**Figure 4.3**).

Table 6.3: Average monthly rainfall data (independent rainfall stations)

Month	Average Rainfall (mm)	Minimum Rainfall (mm)	Year Recorded	Maximum Rainfall (mm)	Year Recorded
October	67	7.2	1917	215.2	1993
November	108.4	15.8	1935	314.4	1917
December	121	15.4	1944	293.4	1942
January	132.5	30.1	1989	440.2	1977
February	106.3	11	1976	395.8	1943
March	93.2	10.6	1964	238.9	1924
April	50.5	0	Often	176.5	1970
May	20	0	Often	162.1	1935
June	7.2	0	Often	105.7	1943
July	7.7	0	Often	98.2	1951
August	9.1	0	Often	96.6	1917
September	21.5	0	Often	123.6	1986
Total	**744.4**				

The following observations are made from a comparison of the tabulated rainfall data:

- Comparison of the reviewed Mean Annual Precipitation (MAP) with that of the WUC (2009) study shows the reviewed MAP (745 mm) to be similar, being about 5.4% higher than the WUC (2009) value of 706 mm; and
- The maximum monthly rainfall based on the review (440 mm in January 1977) is 50% higher than the 292 mm reported for the same month and year by WUC (2009). This could possibly be due to a more accurate and patched rainfall record used for this study, which is based on the rainfall database used by DWA for all resource modelling (Middleton and Bailey, 2005).

6.5.2 Review and verification of ingress volumes

The expected ingress of surface water into the mine workings has a marked influence on the abstraction requirements and hence pumping and maintenance costs. Two approaches have been adopted in trying to assess the predicted ingress volumes and the source:

- Determination of the total ingress into the mine void based on surface flow rates as well as assumptions on the percentage infiltration of surface water into the mine void from various geological formations, mine infrastructure and natural drainage systems (WUC, 2009), as summarised in this section; and
- Determination of the total ingress into the mine void based on mine void volume, water level and pumping data, as described in **Section 6.5.3**.

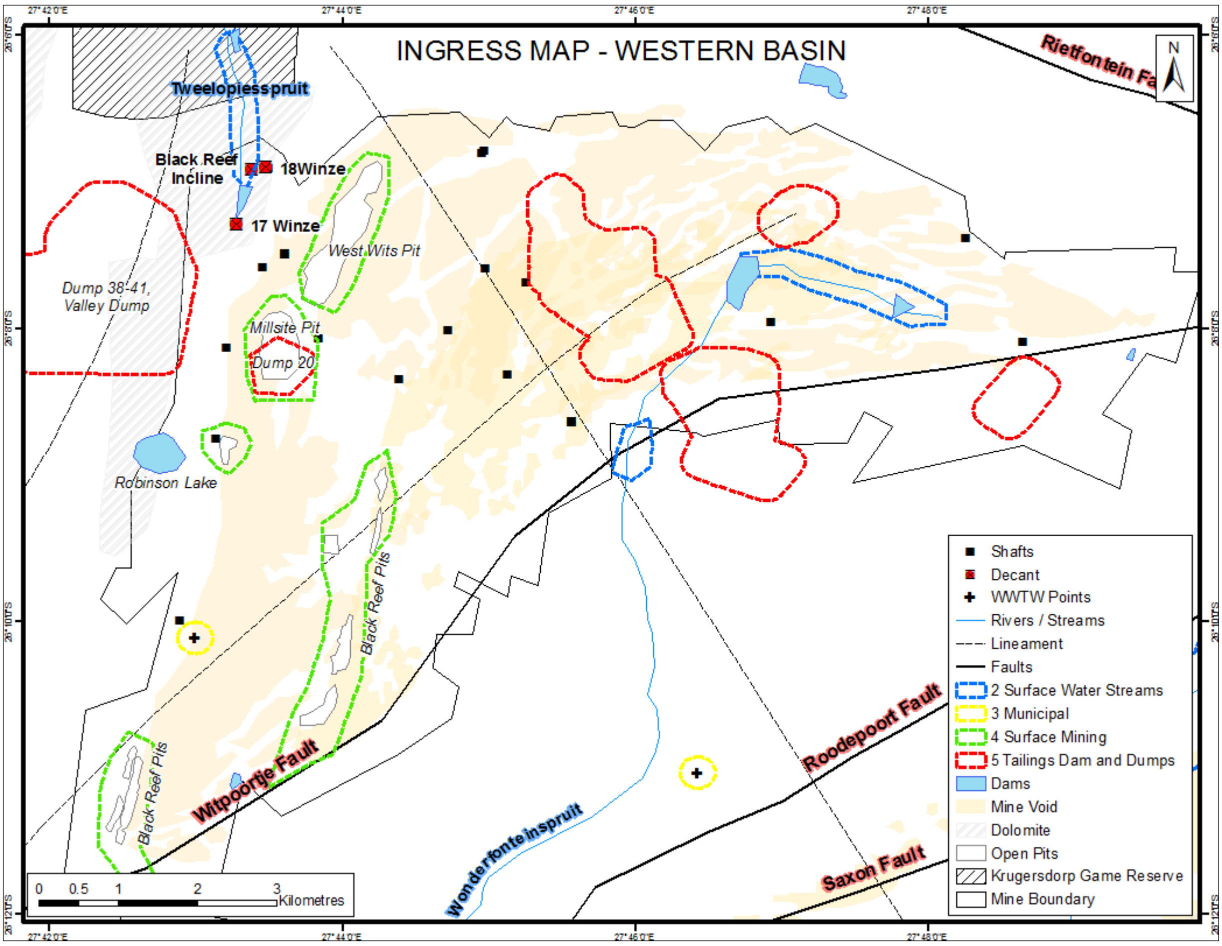
a) Sources of ingress and estimated volumes

Relevant data and assumptions made have been taken principally from the WUC (2009) study on the Western Basin. In addition, the changes in rainfall have also been reviewed in order to consider the impact of rainfall variation on the ingress volumes.

Given in **Table 6.4** are the major ingress areas with relevant comments on the mechanism of ingress into the mine voids in the areas shown in **Figure 6.10**.

Table 6.4: Summary description of ingress areas by source type

No.	Source Type	Detailed Ingress Areas
1	Undisturbed geology /Shallow aquifers	Recharge of a shallow weathered aquifer located above areas of shallow underground mining. The dolomite outlier in the KGR is partially weathered to permeable wad and provides a pathway for direct recharge from precipitation into the hydraulically connected mine voids via the Black Reef workings. The Zwartkrans Compartment dolomite is not hydraulically connected to the mine void.
2	Surface water (dams, rivers, wetlands)	Upper portions of the Wonderfontein Spruit and the storage of water pumped from the void in Robinson Lake and the wetlands below it. Once the hydraulic gradient has been reversed towards the mine void, decant into the Tweelopies Spruit will cease but ingress from the upper reaches of the Tweelopies Spruit may be induced.
3	Municipal infrastructure (leaking mains and sewerage, stormwater runoff)	Leakage of municipal services (sewers and water reticulation) in urbanised areas overlying the mine voids. Ingress of stormwater directed into abandoned surface mining operations observed in the Mogale City Local Municipality.
4	Surface mine workings (open pits, shafts, inclines)	West Wits Pit (being used for sludge disposal) and Millsite Pit are holed directly into the mine void. Ingress into the mine void via open pits along the Witpoortje Fault in the south-western area of the basin.
5	Tailings dams and mine dumps	Very poor quality seepage and stormwater from Dump 20 into adjacent Millsite Pit. Dumps 38-41 and Valley seep into mine void via dolomite wad aquifer.



Numbers in legend refer to source type in the preceding table

Figure 6.10: Major ingress areas in the Western Basin

Based on the average rainfall given in **Table 6.1** as well as flow monitoring, the expected total ingress volume for the Western Basin as defined in the WUC (2009) study is about 16 Mℓ/d. An approximate percentage distribution of the total ingress for each of the sources defined in the WUC (2009) study is tabulated in **Table 6.5**.

Table 6.5: Predicted ingress sources (average rainfall)

Source	Percentage of Total Ingress Volume	Ingress Volume (Mℓ/d)
Groundwater recharge via natural & undisturbed geology	48	7.70
Ingress through reef outcrops	6	0.96
Ingress through rehabilitated & opencast pits	22	3.50
Tailings dams and mine dumps base seepage zones	21	3.36
Ingress from rivers & water bodies	3	0.48
TOTAL	**100**	**16.00**

Source: WUC, 2009

Taking into account that this study is concerned with a long-term solution, it is important to also assess how potential climate change can affect the ingress volume. For this purpose, extreme rainfall variations as well as a potential climate change component have been used to assess the sensitivity of ingress volumes to this long-term variable (**Table 6.2**). The prediction is based on the Goldsim Model utilised by Golder & Associates for the WUC (2009) study.

A summary of the expected ingress volume variation is given in **Table 6.6**.

Table 6.6: Rainfall variation impact on ingress volume, Western Basin

Rainfall	MAP (mm)	Change in MAP (%)	Predicted Ingress (Mℓ/d)	Change in Ingress (%)
Average	705	0.00	15.7	0.00
Dry Season	417	-40.85	12.3	-22
Wet Season	1 052	49.22	16.1	-3
Extremely Wet	1 835	160.28	19.5	24
Climate Change	990.00	40.00	16.00	2

Figure 6.11 shows an example of ponding water at the base of a sand dump in the Western Basin that drains directly into the mine void via the open Millsite Pit.

Figure 6.11: Ponding of water at the base of a large sand dump in the Western Basin

The potential variation in MAP of about 20 - 40% due to climate change could change the ingress volume by about 2% and hence has a minor impact on the ingress volume.

6.5.3 Ingress estimations based on void volume

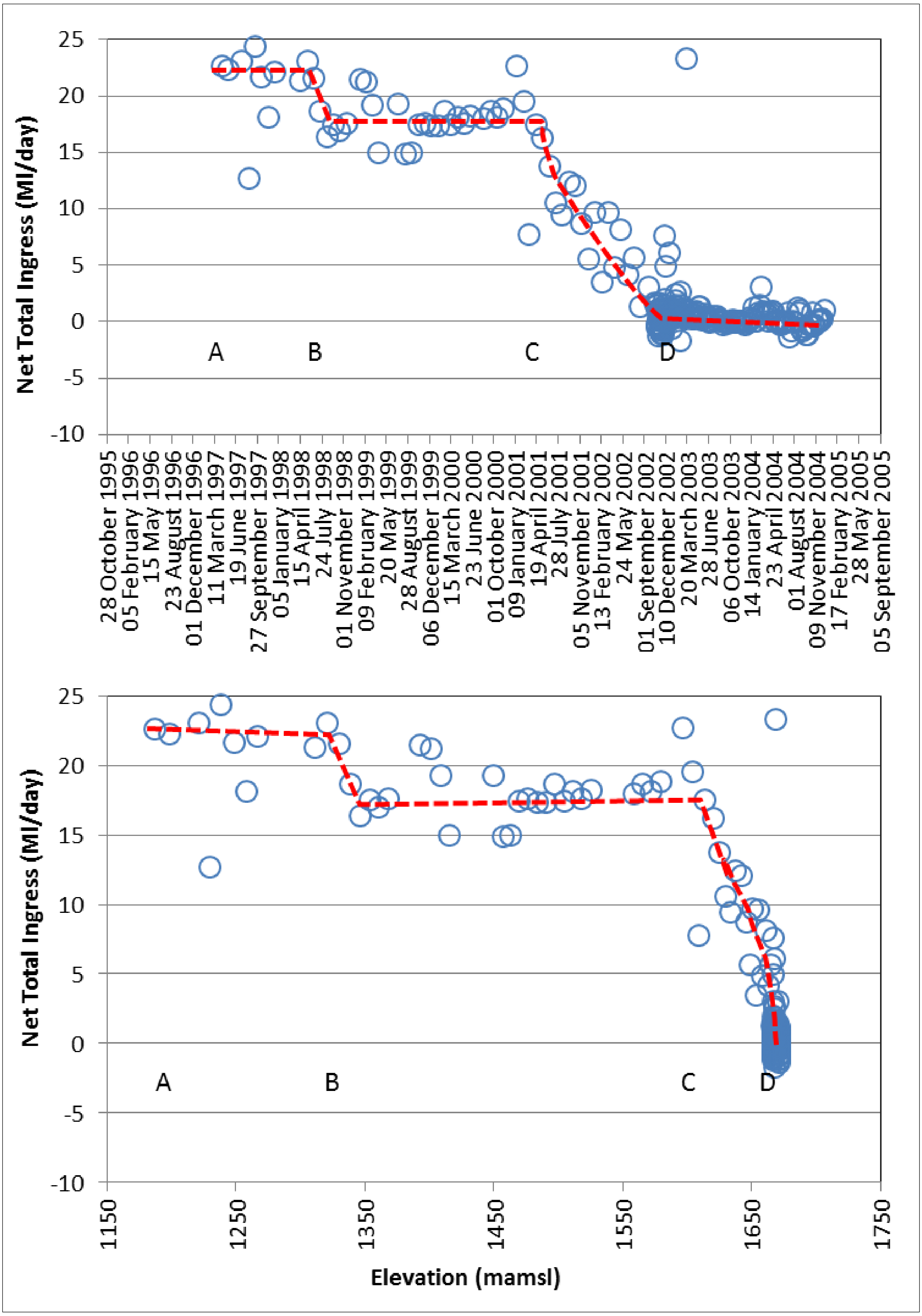
The total ingress (m^3/d) into the mine void is a function of the mine void filling rate (VF; m/d) and the mine void surface area (VS; m^2) at a given filling level (m amsl), i.e.

$$\text{Ingress } (m^3/d) = VF*VS \ (m/d*m^2 = m^3/d).$$

Records of the VF at different elevations are available from April 1997 to December 2004, covering the decant episode from the BRI and the 17 and 18 Winzes. Data for the Central Vent Shaft and CPS borehole was provided by B van der Walt, Rand Uranium (pers. comm., 2012) and H Coetzee, CGS (pers. comm., 2011). Since VS can be obtained from the void data of Rison Consulting as presented in the TCTA (2011) report, it is possible to calculate the apparent total ingress into the Western Basin in the years just prior to the surface decant event in 2002. It is noted that the void volume estimates of Rison Consulting are based on 10 m intervals. This is at variance with the work of Krantz (1996) who quoted 5 m intervals for the same volumes at the same elevations. In this investigation, the original 5 m interval listed by Krantz (1996) is accepted as the correct number.

The results of the calculations are illustrated in **Figure 6.12**. The following observations are relevant:

- The estimated total ingress seems to follow a stepwise reduction as surface decant is approached. This decrease is interpreted to be a reflection of a stepwise increasing void surface area or volume closer to surface, rather than to a true decrease in ingress volumes. A decrease in the hydraulic gradient would be gradual across the depth range and is therefore a less plausible explanation.
- The interpretation presented in **Figure 6.12**) is in part a function of the scatter of the void data. The line of best fit used (**Figure 6.13**) does not satisfy the small scale variation in the void data. An alternative interpretation is to assume a gradual decrease in ingress between points A and C, which would then possibly indicate a decreasing hydraulic gradient. However, although the latter interpretation might have contributed to the process, it is not favoured here due to the distinct flexure of the filling curve at point B in **Figure 6.6.**
- Ignoring the excessive scattering along portions of the graphs, the calculated ingress volumes show no clearly discernible seasonal fluctuation, suggesting that enhanced ingress due to seasonal rainfall is not a major factor. More detailed diagrams (not presented) enforce this notion. This observation is somewhat counter-intuitive but is supported by the fact that the Western Basin forms a well-drained high plateau and that direct natural ingress into the mine void is probably limited as a result. More research into this aspect is clearly indicated.



Note: The estimated net total ingress appears to decrease in a stepwise manner, probably related to changes in the volume of the mine void.

Figure 6.12: Estimated apparent net ingress in the Western Basin

- The difference in estimated ingress volumes between points AB (~22.7 Mℓ/d) and BC (~19.3 Mℓ/d) is interpreted as the merging of two sub-basins – one rising and one perched (similar to the Crown Mines and Durban Roodepoort Deep (DRD) compartments in the Central Basin). Assuming a roughly constant ingress over time, the data suggests that at point B (**Figure 6.12**) the surface area of the void expanded by about 18% between 1 321 and 1 346 m amsl. This compares favourably with a void volume enlargement of ca. 12% between 1 351 and 1 391 m amsl described by Krantz (1996).
- At point C, at a level of ca. 1 610 m amsl, the void water may have entered the Black Reef workings and began to spread into the shallow weathered aquifer in the dolomite outlier. This probably ultimately led to the filling of the Hippo Dam and the reactivation of certain springs in the area (**Figure 6.5**).
- The rate of flow through the shallow aquifer either did not keep up with the volume of water ingress from the void, or the shallow dolomite aquifer may have filled up, or a combination of both, and the final decant on surface (point D, (**Figure 6.12**)) occurred in 2002 in a borehole (CPS) close to the Black Reef Incline (BRI). Small negative elevation levels recorded at point D probably derives from measuring errors (±2 m) in the shafts.
- The absolute estimated ingress volumes of ca. 19 to 23 Mℓ/d (points AB and BC) are lower than the measured average surface decant in the period 2010 to 2011 (**Figure 6.14**) which amounts to ~27 Mℓ/d (Coetzee, pers. comm., 2011). It has been noted that despite efforts to prevent surface runoff reaching the measuring weir, some surface runoff is measured. Nevertheless, the estimated ingress volumes arrived at in this study are significantly larger than the 7 to 12 Mℓ/d estimated by Harmony Gold Mine (WUC, 2009).
- It should be stressed that the numbers for estimated ingress presented here are based on averaged void volume data. This averaging of a less well-behaved line, together with the possible error in the void volume definition, evidently introduced considerable variance to the estimated numbers. The difference between 19 and 23 Mℓ/d is realistically seen as an estimate of the possible error, rather than a difference in true ingress.
- Finally, the filling pattern observed for the Western Basin might well repeat itself, depending on local geological constraints, in the Central and Eastern basins. Most important is the influx of the AMD into the shallow weathered aquifers. Similar subsurface decant into the shallow aquifer, with currently unknown side effects, could be expected in the Central and Eastern basins if the water level is allowed to rise above the ECL.

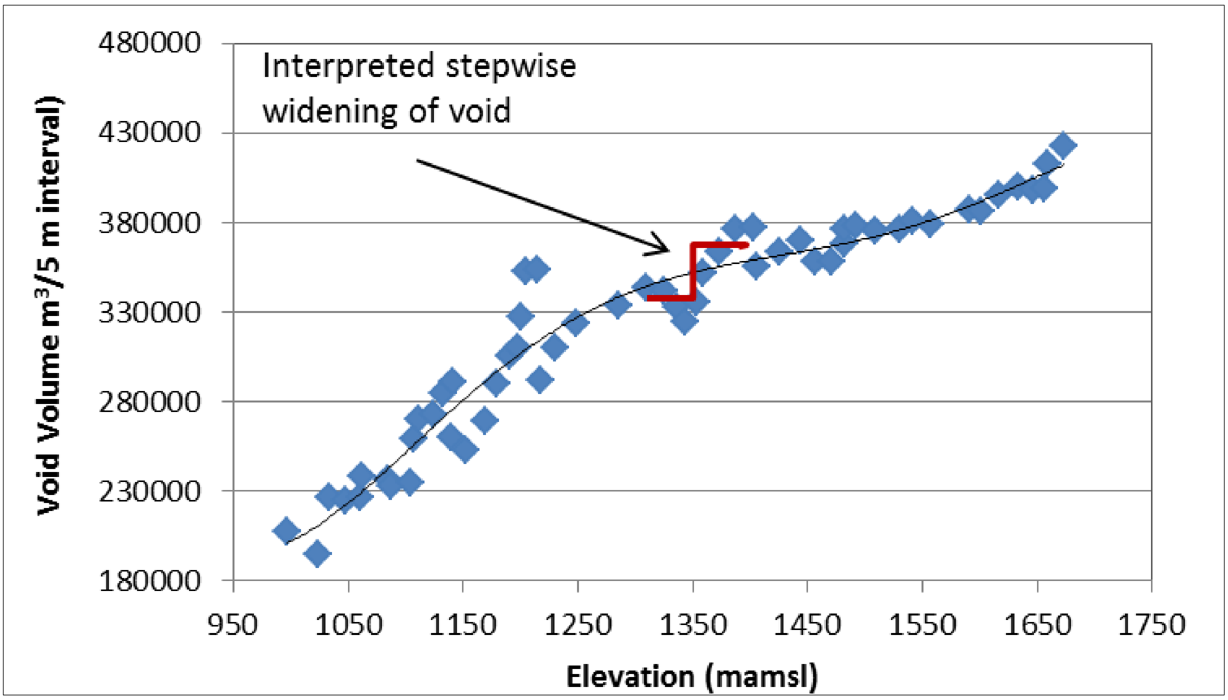
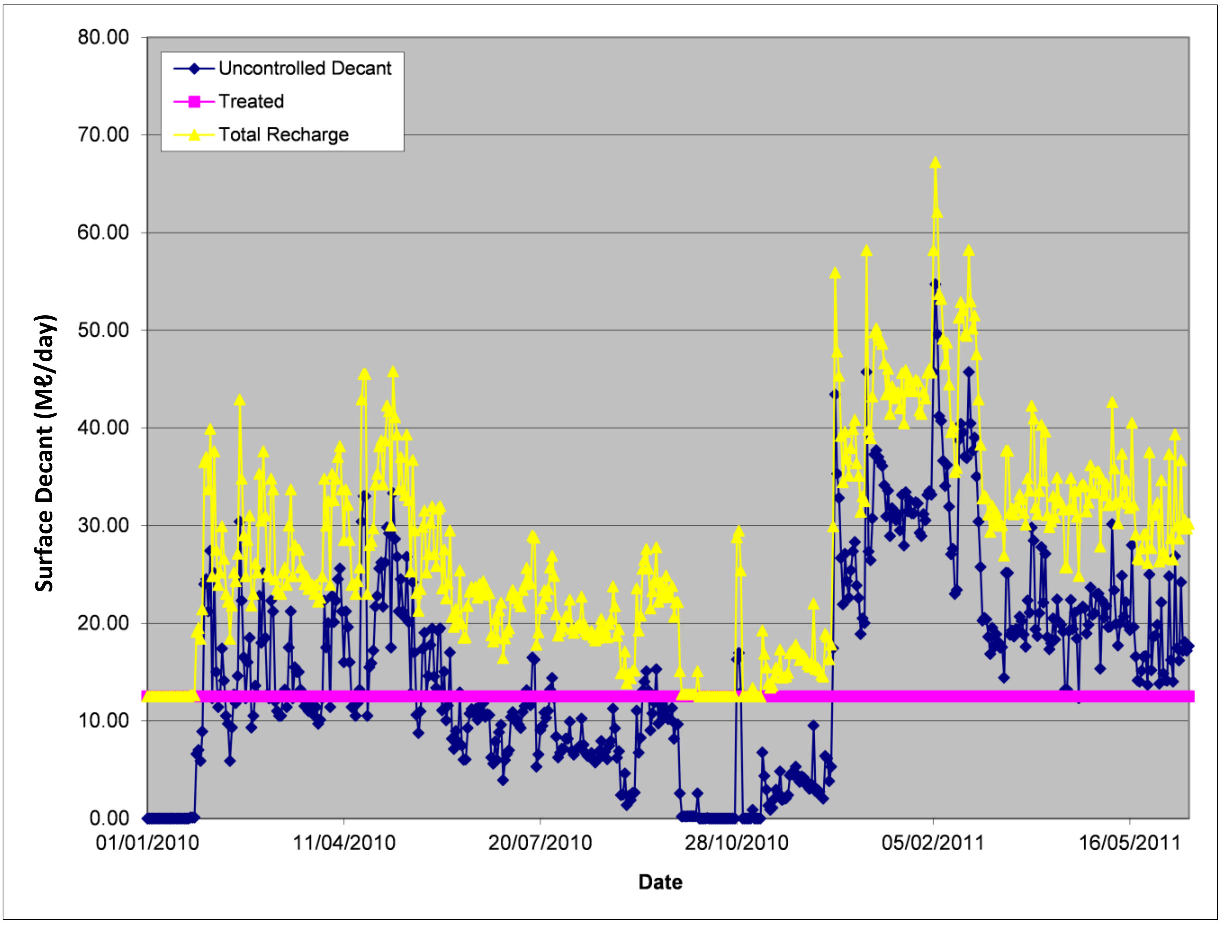


Figure 6.13: Modelled void volume curve used in the ingress volume calculations



Source: Coetzee, personal communication, 2011

Figure 6.14: Measured surface decant of the Western Basin measured by Rand Uranium

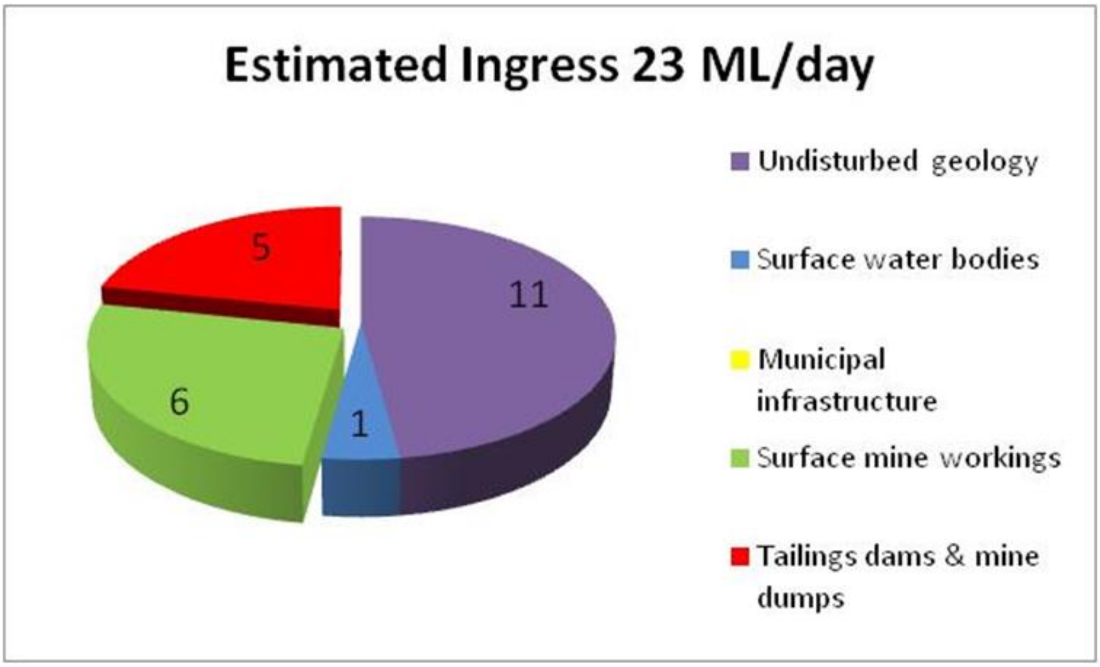
6.5.4 Minimising surface water ingress

The ingress estimated from the void volume study of 19 to 23 Mℓ/d is considered more accurate than that reported in the WUC (2009) study. In order to reduce surface water ingress as much as possible, an initial prioritisation of the main categories of sources defined in **Table 6.4** has been made for the Western Basin, as shown in **Table 6.7**.

Table 6.7: Prioritisation of ingress control measures

Source	Percentage of Total Ingress volume	Expected Ingress Volume (Mℓ/d)	Priority of improved ingress control[1]
Undisturbed geology /Shallow aquifers	48	11	5
Surface water (dams, rivers, wetlands)	3	1	3
Municipal infrastructure (leaking mains and sewerage, stormwater runoff)	0	Low	4
Surface mine workings (open pits, shafts, inclines)	28	6	1
Tailings dams and mine dumps	21	5	2
Total	100	23	

1: A priority "5" has been given to the "Groundwater recharge via natural & undisturbed geology" as no practical and feasible improvements to control ingress can be applied to this source.



Exploded slices indicate sources that can be controlled and inset bars are sources that cannot be controlled.

Figure 6.15: The expected ingress volume for the Western Basin

Table 6.7 and **Figure 6.15** indicate that undisturbed flow through geology accounts for nearly 48% of the total ingress volume. No practical reduction in this ingress via natural strata is possible. The following control measures for the Western Basin, as described in **Section 4.4** and **Appendix C,** should be considered for reducing mine void ingress:

- Rehabilitation of existing open pits and sealing shafts and inclines;
- Removal of mine dumps, currently underway;
- Rivers and other water bodies including possible canalisation of the upper reaches of the Wonderfontein Spruit over areas of surface and shallow underground mining is possible, but should be given a low priority due to the high capital costs; and
- Municipal sources, including upgrade of stormwater drainage systems to reduce ingress into abandoned surface workings in the Mogale City area, of low priority because of a poor cost benefit ratio.

Implementing ingress control and management measures for priority 1 and 2 sources (**Table 6.7**) can theoretically reduce total ingress into the mine void by up to 11 Mℓ/d. Accepting that only half this target is practically achievable reduces ingress to some 5 Mℓ/d, a target that itself justifies efforts to manage historical mine ingress sources where possible. The economic benefits of ingress control are discussed in the Feasibility Report.

6.6 Pumping Volumes and Abstraction Points

6.6.1 Pumping volumes required

Estimates based on void volume and water level rise in the mine void of the Western Basin, over the period 1997 to 2002, suggest an ingress of water in the void of about 19 to 23 Mℓ/day. This exceeds the estimates of 7 to 12 Mℓ/day by Harmony Gold Mines (WUC Report, 2009), the number on which their recent pumping rate of 12.5 Mℓ/day was based. The WUC Report (*op.cit.*) estimates the ingress in the Western Basin at 16 Mℓ/day average (between 11 and 20 Mℓ/day, representing dry and wet seasons, respectively). These numbers are smaller than those from the flume measurements after surface decant (2010-2011; Coetzee, pers. comm.), the latter which suggests a strongly seasonal flow pattern with maxima as high as 50 to 60 Mℓ/day and an average of 27 Mℓ/day. This difference might imply the addition of seasonal rainwater collected by the shallow dolomite aquifer, as well as surface runoff, which is likely to occur in uncovered gauging stations. Whatever the true reason, the numbers estimated by different methods are converging.

A pumping exercise carried out over a period of 13 months (March 2008 to March 2009), abstracting on average 26.57 Mℓ/d, managed to lower the mine water level by approximately three metres (WUC, 2009). This finding broadly supports an ingress rate of ~26 Mℓ/d over the relevant period, which is of similar magnitude to that estimated in this study from the void volume.

In determining a safe pumping rate, the urgency of lowering the water level to ECL and the effect of dewatering the shallow dolomite aquifer that became flooded when the mine water reached a level of 1 610 m amsl (**Figure 6.6** and **Figure 6.12**) needs to be considered. The following water balance calculation is relevant:

Total mine void ingress + Meteoric recharge = Mine void volume + Dolomite aquifer volume

Using the data of Krantz (1996) allows the volume of water that flooded the shallow dolomite aquifer to be estimated (**Table 6.8**), as well as the time needed to empty both the mine void and the shallow aquifer down to 1 610 m amsl.

Table 6.8: Pumping rate outcomes for the Western Basin

<table>
<tr><th colspan="3">Estimates</th></tr>
<tr><td>Rate of ingress in mine void</td><td>25</td><td>Mℓ/day</td></tr>
<tr><td>Time to fill shallow dolomite aquifer plus mine void</td><td>548</td><td>Days</td></tr>
<tr><td>Total ingress over period</td><td>13 700</td><td>Mℓ</td></tr>
<tr><td>Meteoric recharge (10% of 818 mm/a over 5 sq.km)</td><td>40</td><td>Mℓ</td></tr>
<tr><td>Total void ingress plus meteoric recharge</td><td>13 740</td><td>Mℓ</td></tr>
<tr><td>Volume of water stored in mine void</td><td>4 290</td><td>Mℓ</td></tr>
<tr><td>Volume of water in shallow dolomite aquifer</td><td>9 450</td><td>Mℓ</td></tr>
<tr><td rowspan="6">Days to empty dolomite aquifer plus mine void</td><td>Pump rate Mℓ/day</td><td>Years</td></tr>
<tr><td>40</td><td>2.5</td></tr>
<tr><td>50</td><td>1.5</td></tr>
<tr><td>60</td><td>1.1</td></tr>
<tr><td>80</td><td>0.7</td></tr>
<tr><td>100</td><td>0.5</td></tr>
</table>

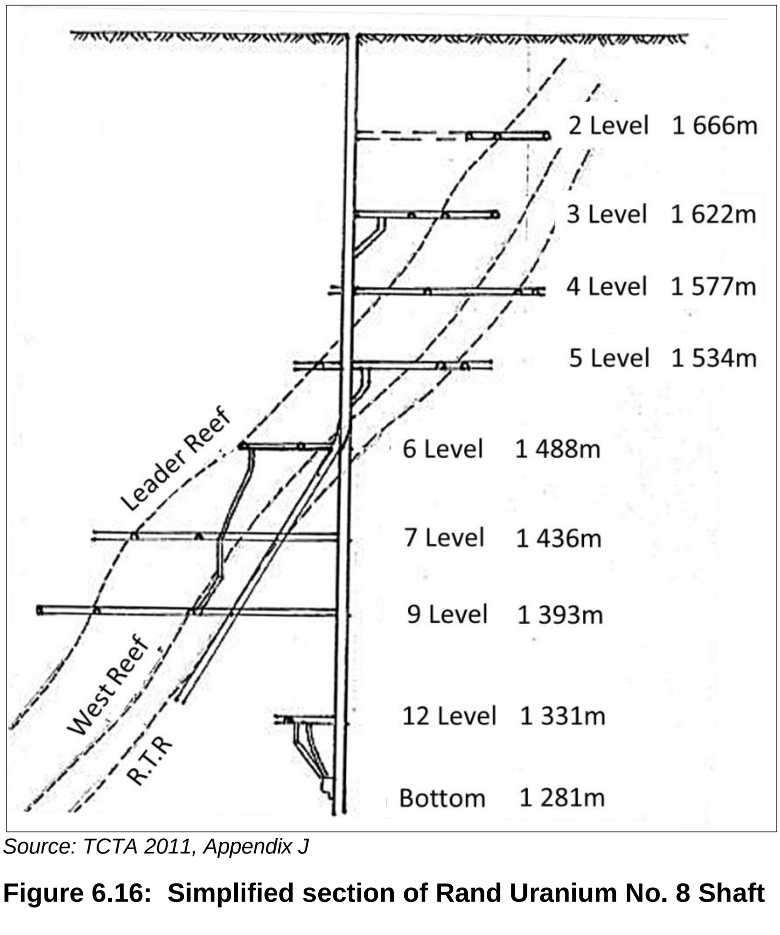
Coetzee (pers. comm., 2011) used the flume-measured surface decant data to calculate a pumping rate of 40 Mℓ/d, which would be adequate to drawn down the water level in the Western Basin to the required ECL over time. This estimate ostensibly only deals with annual ingress in the mine void. When the capacity of the shallow dolomite aquifer is also considered (**Table 6.8**) a total pumping capacity of 60 Mℓ/d is indicated to draw down the AMD level to 1 610 m amsl over one year. Once the ECL is reached, the pumping rate could be lowered to attain steady state conditions.

Currently available data suggests that the pumping rate required in the longer term would probably level off in the range 20 to 27 Mℓ/d and an average of 23 Mℓ/d is proposed. Monitoring of the volumes abstracted and water level drawdown during implementation of the STI will provide critical information toward gauging optimum pumping rates and water levels for the long-term solution.

6.6.2 Suitability of shafts for pumping

Rand Uranium No. 8 Shaft has been chosen by the TCTA for the abstraction of AMD for the Western Basin. Appendix J of the TCTA (2011) study highlights the dearth of information available for this shaft, more data being required to conduct a meaningful stability analysis of the shaft barrel. However, No. 8 Shaft is currently used to pump AMD water using two submersible pumps with a capacity of 8 Mℓ/d each. Initially, the TCTA will be using this capacity as well as pumping from two other locations, No. 9 Shaft and BRI Dam (**Figure 6.5**). The TCTA anticipates that full implementation of the STI will increase pumping capacity in No. 8 Shaft to 27 Mℓ/d on average on a 19-hour day duty schedule, with a maximum of 35 Mℓ/d.

The connectivity of No. 8 Shaft with the mine void has been proven. A simplified section of the shaft shows that it connects to the mine void on multiple levels and at shallow depths (**Figure 6.16**). The shaft collar elevation is at 1 726 m amsl (or 1 723 m amsl, according to Google Earth) and the shaft is 445 m deep.



Source: TCTA 2011, Appendix J

Figure 6.16: Simplified section of Rand Uranium No. 8 Shaft

It is considered preferable to pump from shafts that are well connected with the mine void at shallow levels to maximise the recycling of shallow ingress, leaving the deep, highly contaminated water undisturbed. Turnover of the shallow ingress water will lead to more rapid flushing of the shallow system.

Pumping from a shaft that is connected to the mine void close to surface on multiple levels also ensures connectivity even if there is a collapse on one level. The success of the pumping installation depends on its ability to dewater the entire basin, and ensuring that multiple surface decant does not occur due to a lack of connectivity.

This study has concurred with the STI which concluded that the Rand Uranium Shaft No. 8 is suitably connected to the mine void, but its stability is a concern and the STI is considering using No. 9 Shaft.

6.6.3 Alternative options to pumping

Passive solutions allowing natural surface decant at preferred ECLs, rather than pumping were identified. For the higher ECL, a tunnel could connect the stopes on the West (Main) Reef to a point on surface at the waterfall above the Krugerkloof Lodge in the Krugersdorp Game Reserve. This option will be considered in the options analysis.

6.7 Water Qualities

6.7.1 Data utilised

Water quality data was synthesised from two principal sources:

a) Shaft/adit sampling:

These samples are taken at the water surface in the shaft barrel at Nos. 17 and 18 Winzes or at the outlet of the Black Reef Incline.

b) Surface sampling:

These samples are taken from various monitoring sites within and adjacent to the Krugersdorp Game Reserve, and include dams and canals/pipes channelling mine water discharge.

Two datasets supplied by Rand Uranium were compiled: Dataset A comprised older data spanning the period 2004 to 2009; Dataset B comprised more recent data spanning the period 2011 to 2012. For summary water quality information, Dataset B (summarised in **Table 6.9**) was used as this represented the most current data. Potential bias was observed in Dataset A, possibly from anthropogenic sources.

Table 6.9: Summary of Dataset B

Location	Sample Type	Source	n
17 Winze	Shaft/adit Decant Point	Rand Uranium/CGS	36
18 Winze	Shaft/adit Decant Point	Rand Uranium/CGS	57
Black Reef Incline (BRI)	Shaft/adit Decant Point	Rand Uranium/CGS	55
Charles Fourie Dam	Surface Monitoring Point	Rand Uranium/CGS	57
Downstream Brick Dam Game Reserve	Surface Monitoring Point	Rand Uranium/CGS	58

Location	Sample Type	Source	n
Entrance to Lion Camp	Surface Monitoring Point	Rand Uranium/CGS	58
Hippo Pool	Surface Monitoring Point	Rand Uranium/CGS	58
Inlet to Game Reserve A Seepage	Surface Monitoring Point	Rand Uranium/CGS	58
Inlet to Game Reserve B Canal at Flume	Surface Monitoring Point	Rand Uranium/CGS	58
Inlet to Game Reserve Combination of A + B Total Inlet to Game Reserve	Surface Monitoring Point	Rand Uranium/CGS	42
Lion Camp Dam (Aviary)	Surface Monitoring Point	Rand Uranium/CGS	58
Pipe 7, Porra Dam	Surface Monitoring Point	Rand Uranium/CGS	57
Total			652

n = Number of samples

6.7.2 Water chemistry

A summary of the water quality for a number of sites (Dataset B) in the Western Basin are listed in **Table 6.10**. Of special interest are Nos. 17 and 18 Winzes and the Black Reef Incline (BRI), the three known point-source surface decant sites in the Western Basin (**Section 6.3.2**). Except for slight pH differences, the water quality in the three surface decant sites is almost identical. The BRI AMD, and to some extent that of No. 18 Winze, is slightly more neutral than the No. 17 Winze AMD.

Table 6.10: Water quality (95 percentiles) of selected sites in the Western Basin

Parameter	pH*	EC	SO4	Na	Fe	Ca	Mn	U	TDS^	Acidity
Unit	@25°C	mS/m @25°C	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ U	mg/ℓ	mg/ℓ
17 Winze	3.45	417	3 253	209	895	658	85	-	4 879	1 373
18 Winze	4.18	446	3 658	66	968	713	76	-	5 487	1 525
BRI	4.62	435	3 577	199	923	724	94	-	5 366	1 540
Hippo Pool	2.79	414	3 144	225	369	874	92	0.12	4 715	978
Lion Camp Entrance	2.60	373	2 702	254	238	743	85	0.07	4 052	885
Lion Camp Aviary	2.60	358	2 574	230	207	698	69	0.08	3 860	849
Brick dam GR	2.60	357	2 690	206	193	857	76	0.07	4 035	840
Total Inlet GR	2.80	412	3 210	242	459	701	123	0.10	4 815	1 028
Inlet GR Seepage	2.59	427	3 463	244	480	874	209	0.10	5 194	1 151
Inlet GR Flume Canal	5.69	400	2 909	249	7	885	32	0.02	4 364	95
Porra Dam Pipe 7	2.88	422	3 280	235	720	739	91	-	4 920	1 141
C. Fourie Dam	2.68	374	2 762	201	298	635	75	0.14	4 143	922
*5th Percentile GR – Krugersdorp Game Reserve ^ TDS estimated										

Data source: B. van der Walt, Rand Uranium, March 2012.

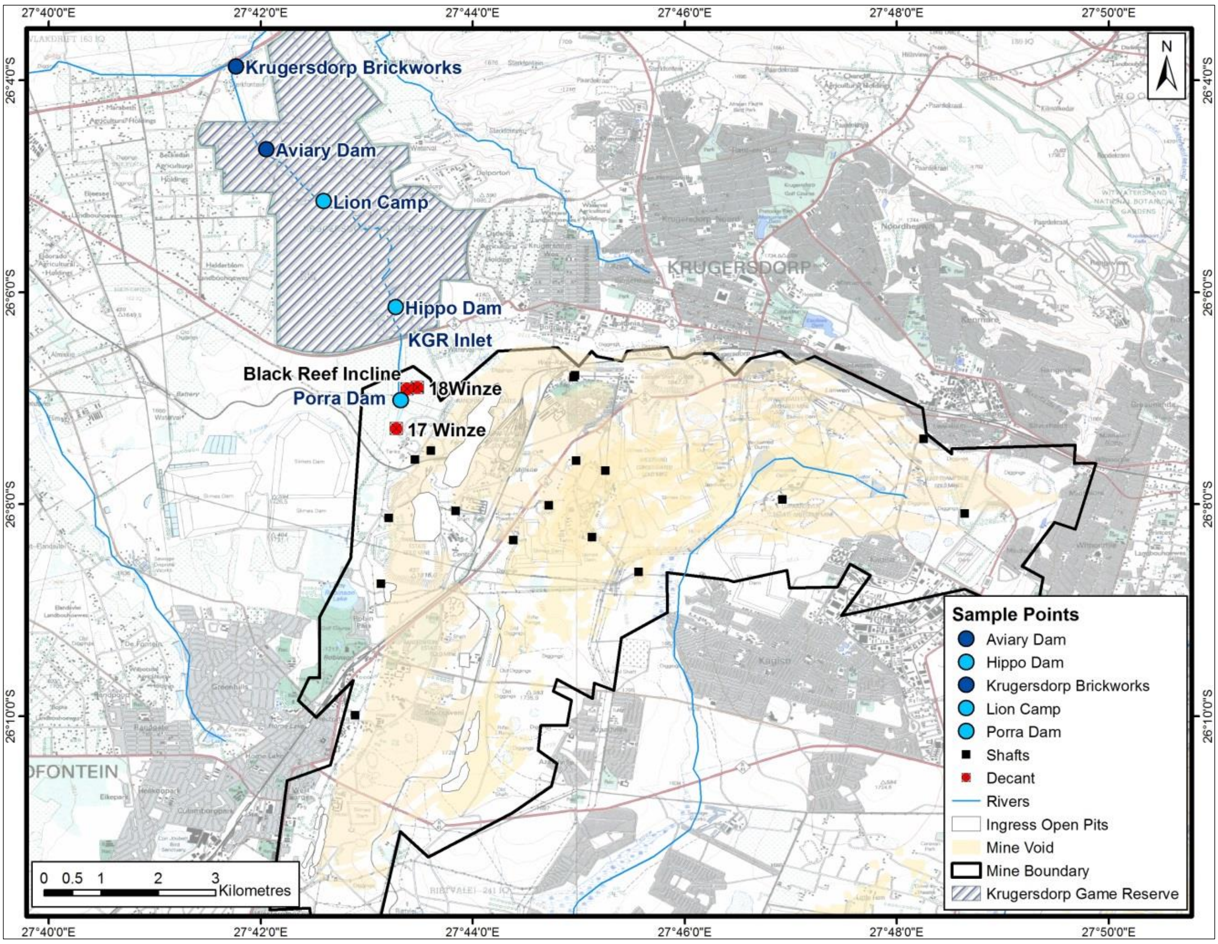


Figure 6.17: Locations of key water chemistry sample sites

It is noticeable that the pH values for the three surface decant sites are on average higher than for the sites lower down the Tweelopies Spruit. This discrepancy may suggest:

- diverse sources and/or channelling pathways for the AMD escaping from the mine void (**Section 6.5**) and could result in variability of the quality of the water, especially during the initial phases of pumping; and/or
- The slow oxidation of ferrous iron and hydrolysis to insoluble ferric hydroxide may also account for the persistence of low pHs downstream of the surface decant, as demonstrated in the Natal Spruit by Naicker et al. (2003).

The total observed range for the AMD from the Western Basin is given in **Table 6.11**.

Table 6.11: Water quality range (percentiles) of the combined data for the Western Basin

Parameter	Unit	Percentile						
		5th	10th	50th	60th	75th	90th	95th
pH	@ 25ºC	2.7	2.8	3.2	3.3	5	5.9	6.5
EC	mS/m@ 25ºC	291	311	363	374	390	412	426
TDS^	mg/ℓ	3 381	3 523	4 313	4 487	4 748	5 092	5 388
Acidity	mg/ℓ	21	194	719	825	965	1 086	1 255
Ca	mg/ℓ	419	458	544	561	597	723	823
Na	mg/ℓ	65	78	101	106	125	175	243
Fe	mg/ℓ	1	21	185	277	463	699	799
Mn	mg/ℓ	11	27	56	62	70	90	114
SO_4	mg/ℓ	2 140	2 230	2 730	2 840	3 005	3 223	3 410
^ Estimated n=651 for all parameters Data accumulated between January 2011 and March 2012								

Using the current data, the most suitable approximation for the expected water quality for abstraction is based on the principal decant sites only (Nos. 17 and 18 Winzes and BRI) and is given in **Table 6.12**.

Table 6.12: Expected water quality (percentiles) for the Western Basin

Parameter	Unit	Percentile				
		5th	10th	50th	90th	95th
pH#	@ 25˚C	6	5.9	5.4	3.9	3.5
EC	mS/m @ 25˚C	320	334	385	434	442
TDS^	mg/ℓ	3 549	4 031	4 628	5 208	5 434
Acidity	mg/ℓ	794	864	1 039	1 406	1 520
Ca	mg/ℓ	424	470	549	633	703
Na	mg/ℓ	65	86	110	175	227
Fe	mg/ℓ	358	439	662	890	954
Mn	mg/ℓ	31	38	56	81	89
SO_4	mg/ℓ	2 366	2 687	3 085	3 472	3 623
^Estimated n = 148 for all parameters Data accumulated between January 2011 and March 2012						
# pH values in reverse percentile order, e.g. 95th percentile is 5th percentile						

6.7.3 Change of water quality with time

Documentation supporting the notion of improvement of water quality with time has been provided by Hobbs (2011) and Goga (2011). **Figure 6.18** illustrates the observed improvement with time of water from the Western Basin. Likewise, it has been observed that the uranium content over the past 9 years of water decanting on surface from the Western Basin, has reduced from over 6 000 µg/ℓ initially to 100-200 µg/ℓ. This decrease is probably due to less U being mobilised from the mine void (Winde *et al*., 2011).

For No. 17 Winze, the data is highly variable (**Figure 6.19**). Until 2007, the water from this shaft was relatively uncontaminated, but deteriorated abruptly in early 2008. This sudden change in chemistry is interpreted to derive from chemical layering in the winze water column, with a column of fresh water from surface ingress probably sitting on deeper noxious AMD. Alternatively, an inappropriate sampling procedure may have contributed to this result but his possibility could not be validated.

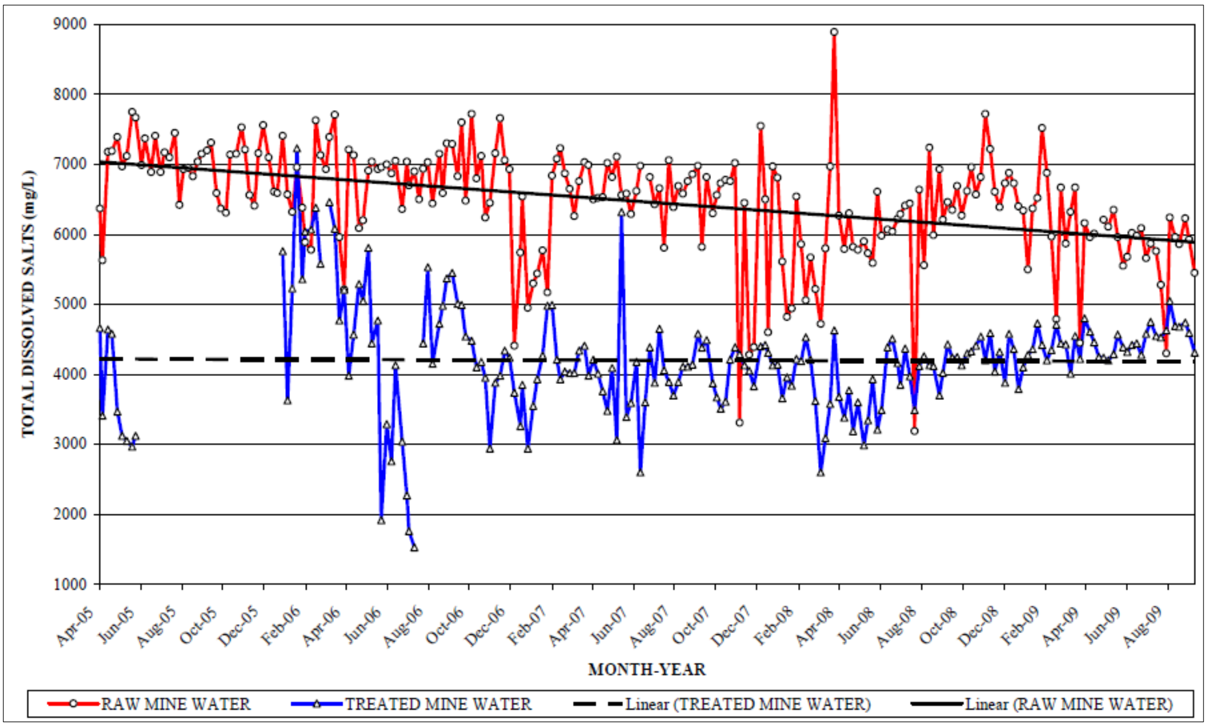


Figure 6.18: Long-term trend of TDS in raw and treated/discharged mine water (Hobbs, 2011)

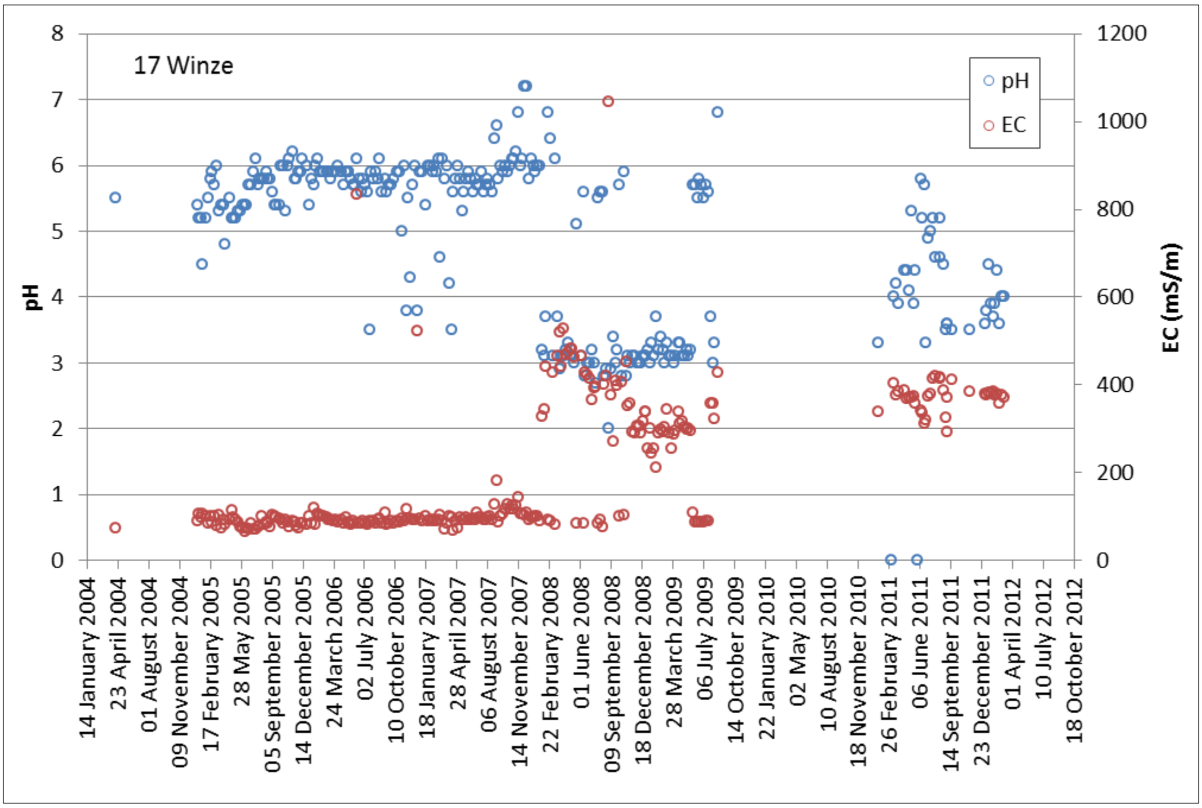


Figure 6.19: Chemical change of the No. 17 Winze water

At No. 18 Winze, the water shows a continuous improvement (decrease) in EC **Figure 6.20**, as well as a rise in pH. It is possible that some mixing of AMD and dolomite water is taking place at this site, as suggested by the high pH measured in 2011.

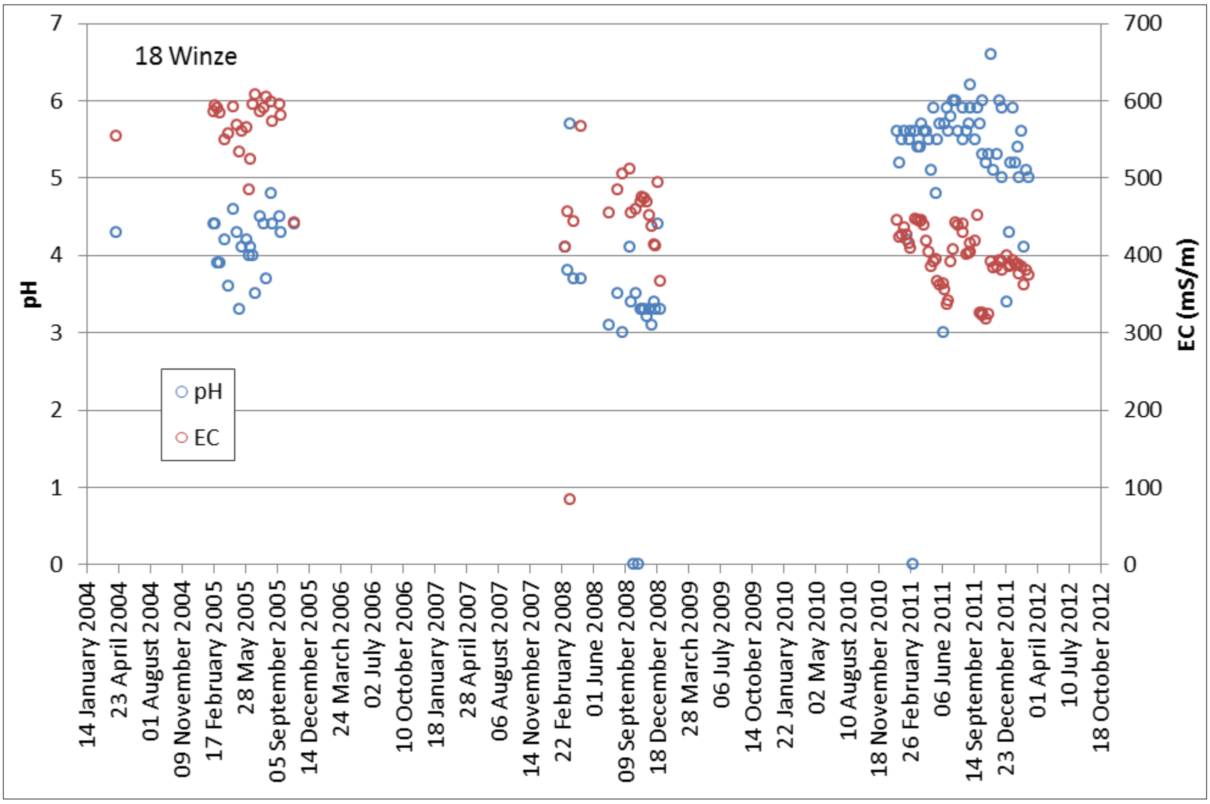


Figure 6.20: Chemical change of the No. 18 Winze water

At the BRI, the water quality is more consistent over time than at the Winze sites (**Figure 6.21**). The EC values are declining, whereas the pH values are at more alkaline levels. The buffering effect of dolomite is inferred from the high Mn contents of the BRI water (**Figure 6.22**) relative to the Winze surface decant water.

On a note of caution, it must be pointed out that in **Figure 6.19** and **Figure 6.20**, the initial ECs measured approached 550 to 600 mS/m. If the model conversion equation (TDS ~11*EC) is applied, the TDS estimates come to between 6 000 and 6 600 mg/ℓ, which is much higher than currently measured elsewhere in the Western Basin. This observation underscores the inherent AMD variability that could possibly be expected during the pumping process.

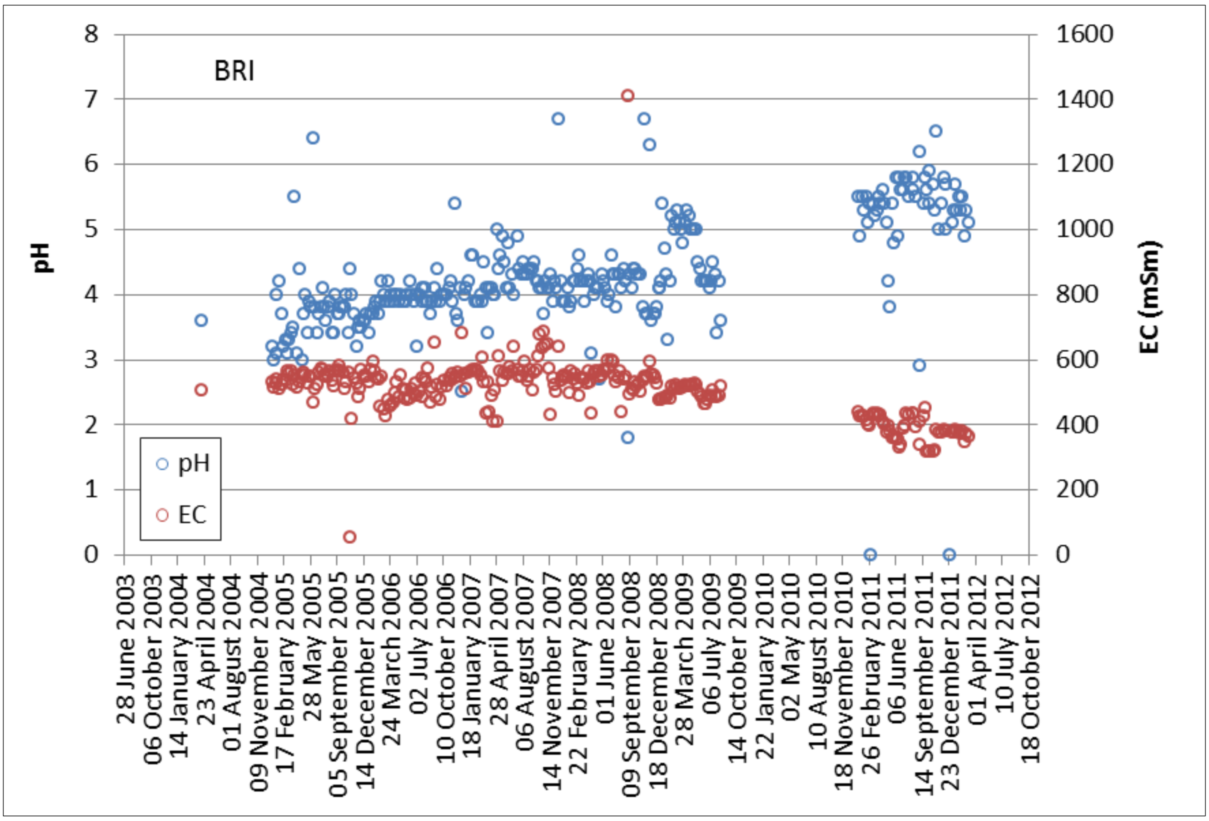


Figure 6.21: Chemical change of the BRI water

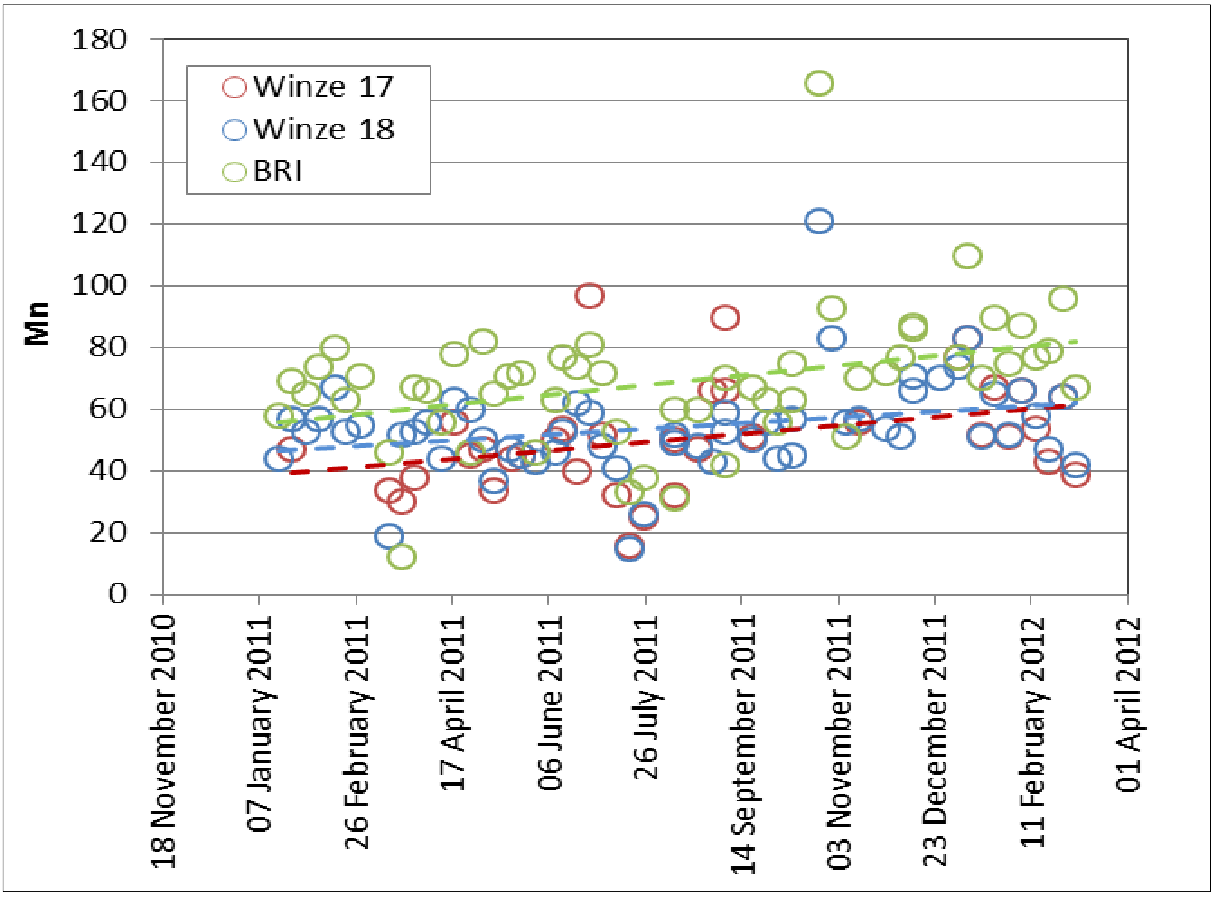


Figure 6.22: Mn concentration (mg/ℓ) in mine water decant water of the Western Basin

6.8 Summary and Recommendations

6.8.1 Water levels and ECL

In the Western Basin, to reduce the associated risks to the Sterkfontein dolomite aquifer that hosts the Cradle of Humankind due to decant from the void into the Tweelopies Spruit, the water level could be lowered to the static water level which equates to the proposed ECL or TOL of 1 600 m amsl and held there for an appropriate duration to establish whether the current situation downstream improves. It is noted that, depending on the rate of pumping it could take 1 to 2 years to reach equilibrium across the void. If leakage of direct AMD in the lower reaches of the Tweelopies Spruit ceases then the water could be held at this level, if not it could be lowered further to the more conservative 1 550 m amsl ECL proposed in the TCTA (2011) report. For a detailed comparison of the important water levels chosen in this and previous reports, please refer to **Table 6.14**.

6.8.2 Ingress

The ingress control measures that could theoretically be implemented (i.e. reducing ingress from the open and backfilled pits and removal/re-working of tailings dams) would reduce ingress by about 11 Mℓ/d (48%), Tempering this target with what is practically achievable reduces ingress to a more likely target of 5 Mℓ/d. The remainder of the ingress sources would be difficult and very costly to control and hence have not yet been taken into account. A detailed follow-up study would be required to assess the practicality as well as cost implications.

A summary of the ingress predictions with and without ingress control measures derived from various information sources are given in **Table 6.13**.

Table 6.13: Summary of predicted ingress volumes, Western Basin

Information source	Predicted ingress volume (Mℓ/d), no ingress control		Predicted Ingress Volumes (Mℓ/d), with improved Ingress Control	
	Average	Range	Average	Range
WUC (2009)	18	16 - 20	13	11 - 15
This Study	23	19 – 27	18	14 - 22
TCTA (planned average pumping rate)	27	23 - 35	22	18 – 30

The following observations are made from **Table 6.13**:

- Data from this study compares well with the WUC data; and
- The TCTA planned pumping rates are well in excess of the predicted ingress volumes and would also cater for possible climate change and wetter than average years.

6.8.3 Pumping rates

To account for the accumulated water in the shallow dolomite aquifer (**Section 6.6.1**), an initial pumping rate of up to 60 Mℓ/d is proposed for the immediate and short-term intervention. This would lower the mine water level to 1 600 m amsl in approximately one year if required. Once the required ECL/TOL is reached, the pumping rate could be lowered to maintain steady state (quasi-equilibrium) conditions. Data indicates that the pumping rate in the longer term would probably level off in the range of 20 to 27 Mℓ/d, with an average of 23 Mℓ/d. Based on the interconnectivity with the mine void, the selected STI abstraction point at Rand Uranium No. 8 Shaft is considered to be appropriate for the long-term solution.

6.8.4 Water quality

The Western Basin AMD currently reflects an EC of ca. 350 mS/m, which represents about 3 850 mg/ℓ of total dissolved solids (TDS), with a 95th percentile value of 426 mS/m (about 5 400 mg/ℓ TDS). Recorded pH values vary between 2 and 7, depending on the measure of neutralisation that probably reflects differing degrees of interaction with dolomitic water. The slow oxidation of ferrous iron to insoluble ferric hydroxide provides a logical explanation for the persistence of low pH values downstream of the surface decant.

Table 6.14: Comparison of key surface levels in the Western Basin

<table>
<tr><th colspan="14">Western Basin - Comparison of Surface Levels at key locations and recommended ECLs, SECLs and TOLs</th></tr>
<tr><th>Source Document</th><th>Decant Level (m amsl)</th><th>Decant Point</th><th>ECL (m amsl)</th><th>Proposed Target Operating Level (m amsl)[1]</th><th>Depth of Proposed TOL (m) below lowest decant point</th><th>Rationale for Proposed TOL</th><th>Level not to be exceeded (e.g. bottom of aquifer)</th><th>Surface level at location of feature to be protected (m amsl)</th><th>Depth from surface to feature to be protected (m)</th><th>Other Considerations</th><th>Abstraction Shaft</th><th>Abstraction Shaft Collar Level (m amsl)</th><th>Depth of proposed TOL at Abstraction Shaft (m)</th></tr>
<tr><td rowspan="2">IMC report (Dec 2010)[2]</td><td>1 680</td><td>Black Reef Incline & 18 Winze and 17 Winze</td><td>1 530</td><td>1 530</td><td>150</td><td>Protection of dolomitic groundwater in the Cradle of Humankind</td><td>Not given</td><td>Not given</td><td>Not given</td><td>None given</td><td>Not given</td><td>Not given</td><td>Not given</td></tr>
<tr><td>Not given in report, calculated from depth and ECL. 1 530 + 150 = 1 680</td><td>Chapter 6.4.1, page 49, first paragraph</td><td>Table 7.4, page 65</td><td>Not defined, assumed to be equal to ECL of 1 530 m amsl</td><td>Table 10.1</td><td>Table 10.1</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">TCTA Due Diligence Report (2011)[3]</td><td>1 680</td><td>Black Reef Incline & 18 Winze and 17 Winze</td><td>1 600</td><td>1 550</td><td>130</td><td>50 m below base of dolomite outlier. If the mine water pumping level is maintained below the base of the dolomite outlier, groundwater flow will be towards the mine and seepage towards the Sterkfontein dolomite will be minimized.</td><td>1 600</td><td>Not given</td><td>Not given</td><td>None given</td><td>Rand Uranium No. 8 Shaft</td><td>1 715.3</td><td>165.3</td></tr>
<tr><td>Table 1, page 10</td><td>Table 1, page 10</td><td>Assumed to be level quoted for the base of the dolomite</td><td>50 m below base of dolomite</td><td>Decant Level minus TOL</td><td>Table 1 of report and Chapter 2 of Annexure B</td><td>Annexure B</td><td>N/A</td><td>N/A</td><td>N/A</td><td>Chapter 6.3.1</td><td>Table 11</td><td>No. 8 Shaft Collar Level - TOL</td></tr>
<tr><td rowspan="3">Long-term Solution[4]</td><td>1 669</td><td>Black Reef Incline</td><td>Initial ECL: 1 600</td><td>Initial TOL: 1 585</td><td>Initial Depth: 84</td><td>To prevent the water from the mine void entering the dolomitic aquifer via the Black Reef mine workings at approximately 1 610 m amsl.</td><td>1 610</td><td>Not given</td><td>Not given</td><td>None given</td><td>Rand Uranium No. 8 Shaft</td><td>1 726</td><td>141</td></tr>
<tr><td colspan="2" rowspan="2">This report, Chapter 6. Collar levels are given for BRI (1669), 17 Winze (1679) and 18 Winze (1677).</td><td>This report, Chapter 6</td><td>Prefeasibility Report, 1st draft, Table 2.5, page 17</td><td>Decant Level minus Initial TOL</td><td>This report, Chapter 10</td><td>This report, Chapter 10</td><td>N/A</td><td>N/A</td><td>N/A</td><td rowspan="2">This report, Chapter 6.</td><td rowspan="2">This report, Chapter 6</td><td>No. 8 Shaft Collar Level - Initial TOL</td></tr>
<tr><td>Conservative ECL: 1 565</td><td>Conservative TOL: 1 550</td><td>Conservative Depth: 119</td><td>If leakage into Black Reef workings occurs at TOL = 1 585, it should be lowered further, i.e. towards the 1 550 m amsl conservative TOL.</td><td>1 610</td><td>Not given</td><td>Not given</td><td>None given</td><td>176</td></tr>
</table>

Western Basin - Comparison of Surface Levels at key locations and recommended ECLs, SECLs and TOLs													
Source Document	**Decant Level (m amsl)**	**Decant Point**	**ECL (m amsl)**	**Proposed Target Operating Level (m amsl)[1]**	**Depth of Proposed TOL (m) below lowest decant point**	**Rationale for Proposed TOL**	**Level not to be exceeded (e.g. bottom of aquifer)**	**Surface level at location of feature to be protected (m amsl)**	**Depth from surface to feature to be protected (m)**	**Other Considerations**	**Abstraction Shaft**	**Abstraction Shaft Collar Level (m amsl)**	**Depth of proposed TOL at Abstraction Shaft (m)**
			Technical Prefeasibility Report	Technical Prefeasibility Report	Decant Level minus Conservative TOL	This report, Chapter 10	This report, Chapter 10	N/A	N/A	N/A			No. 8 Shaft Collar Level - Conservative TOL

1: The "freeboard" (or buffer) proposed for the LTS, being the difference between the ECL/SECL and the TOL was estimated for the long-term for when conditions are stable. A larger freeboard would be appropriate for the short-term, until seasonal and spatial variations of the water level have been established.

2: Expert Team of the Inter-Ministerial Committee (2010) Mine water management in the Witwatersrand gold fields with special emphasis on Acid Mine Drainage. Report to the Inter-Ministerial Committee on Acid Mine Drainage. Council for Geoscience. December 2010, 128 pp.

3: Seath, S.G. and van Niekerk, J.A. Due Diligence Report: Witwatersrand Gold Fields Acid Mine Drainage (Phase 1). Report compiled by BKS (Pty) Ltd in association with Golder Associates on behalf of Trans Caledon Tunnel Authority (TCTA). 126 pp.

5: DWA AMD FS 2012, Study Report No. 5: Technical Prefeasibility Report

Table 6.15: Western Basin Critical Levels

Level (m amsl)	Level (m amsl)	Black Reef Incline		Rand Uranium No. 8 Shaft		Mintails No. 9 Shaft		Winze No. 17		Winze No. 18		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 800												
1 790												
1 780												
1 770												
1 760												
1 750												
1 740												
1 730	1 726			Abstraction Shaft Collar Level	0							RU #8 is 445 m deep
1 720	1 716					Surface	0					Level from Google Earth
1 710												
1 700												
1 690	1 679							Surface	0			
1 680	1 677									Surface	0	
1 670	1 669	Surface (Decant point)	0									Decant point
1 660	1 666			2 Level	60		50					
1 650	1 656		13		70		60		23		21	Bottom of West Wits Pit (as estimated from Google Earth at 26°07'38.88"S, 27°43'56.02"E)
1 640												
1 630												

Level (m amsl)	Level (m amsl)	Black Reef Incline		Rand Uranium No. 8 Shaft		Mintails No. 9 Shaft		Winze No. 17		Winze No. 18		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 620	1 622		47	3 Level	104		94		57		55	
1 610	1 610		59	Non-exceedance level at BRI	116		106		69		67	To prevent the water from the mine void entering the dolomitic aquifer via the Black Reef mine workings at approximately 1 610 m amsl.
1 600	1 600		69	Initial ECL	126		116		79		77	Also ECL for STI
1 590	1 585		84	Initial TOL	141		131		94		92	
1 580	1 577		92	4 Level	149		139		102		100	
1 570	1 565		104	Conservative ECL	161		151		114		112	
1 560 1 550	1 550		119	Conservative TOL	176		166		129		127	Also TOL for STI
1 540 1 530	1 534		135	5 Level	192		182		145		143	
1 520 1 510 1 500	1 488		181	6 Level	238		228		191		189	

7 CENTRAL BASIN

7.1 Geological Setting

The Central Basin extends from Durban Roodepoort Deep (DRD) in the west, where the reefs terminate against the Roodepoort Fault, to East Rand Proprietary Mines (ERPM) in the east, a distance of about 55 km. The West and Central Rand Group strata dip towards the south at angles varying from vertical (even occasionally overturned) to as little as 20° (**Figure 7.1**).

The Black Reef Formation and the overlying dolomite of the Transvaal Supergroup outcrop well to the south of the Witwatersrand Supergroup rocks, and are mostly separated from them by volcanic rocks of the Ventersdorp Supergroup except for a small region in the west (south of DRD), where the Black Reef fills a deep syncline in upper Central Rand Group rocks. The separation of the Black Reef from the main gold-bearing strata means that the dolomite has no impact on mine water in this basin, and vice versa.

7.2 Hydrogeological Setting

Figure 7.2 shows the conceptual hydrogeological model in a cross-section through the Central Basin from north to south. In the absence of dolomite in proximity to the mined area, only the shallow weathered aquifer associated with the Witwatersrand and Ventersdorp rocks is present. Hydraulic connectivity with the mine voids is via joints, faults and intrusive dykes.

According to Brink (1979), there is a trough-like depression along the total strike of the Jeppestown Subgroup that was occupied by pans and marshes before development in the area, indicating a shallow groundwater table. Even after the reefs were mined, the groundwater strike depths and rest water elevations are normal for this climatic region (Hodgson, 1993). This suggests that no wide cone of dewatering has developed in the shallow weathered aquifer around the mines. This groundwater resource is used locally for irrigation of gardens and golf courses in the highly urbanised Central Basin, and also provides base flow to the streams and rivers that originate in the Witwatersrand quartzite ridges and ultimately flow into the Vaal River. For this reason, protection of the shallow aquifer must be considered and the underlying mine void water should ideally remain below the “base” of the weathered aquifer estimated to be a maximum of 100 m below ground level.

The weathered intrusions in the old workings at shallow depths (<300 m) were zones of seepage, providing preferential flow paths. When the mine development cut through these zones, the preferential flow was called an inrush. Typically, the flows would have diminished as the storage drained from the more permeable structures into the void. At deeper levels, these zones (typically fractured) would have been sealed by grouting.

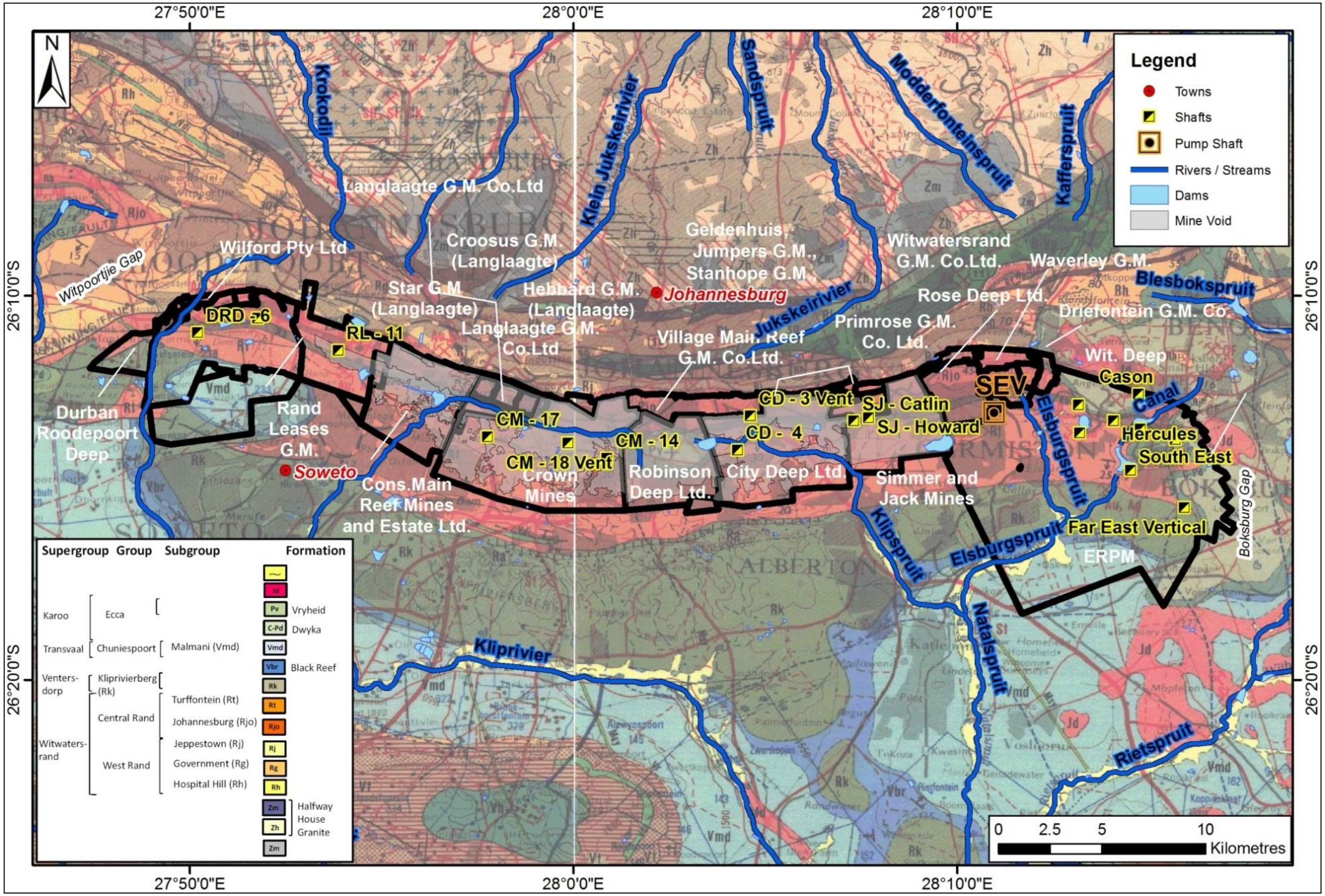


Figure 7.1: Geological map of the Central Basin showing mine boundaries and selected shafts

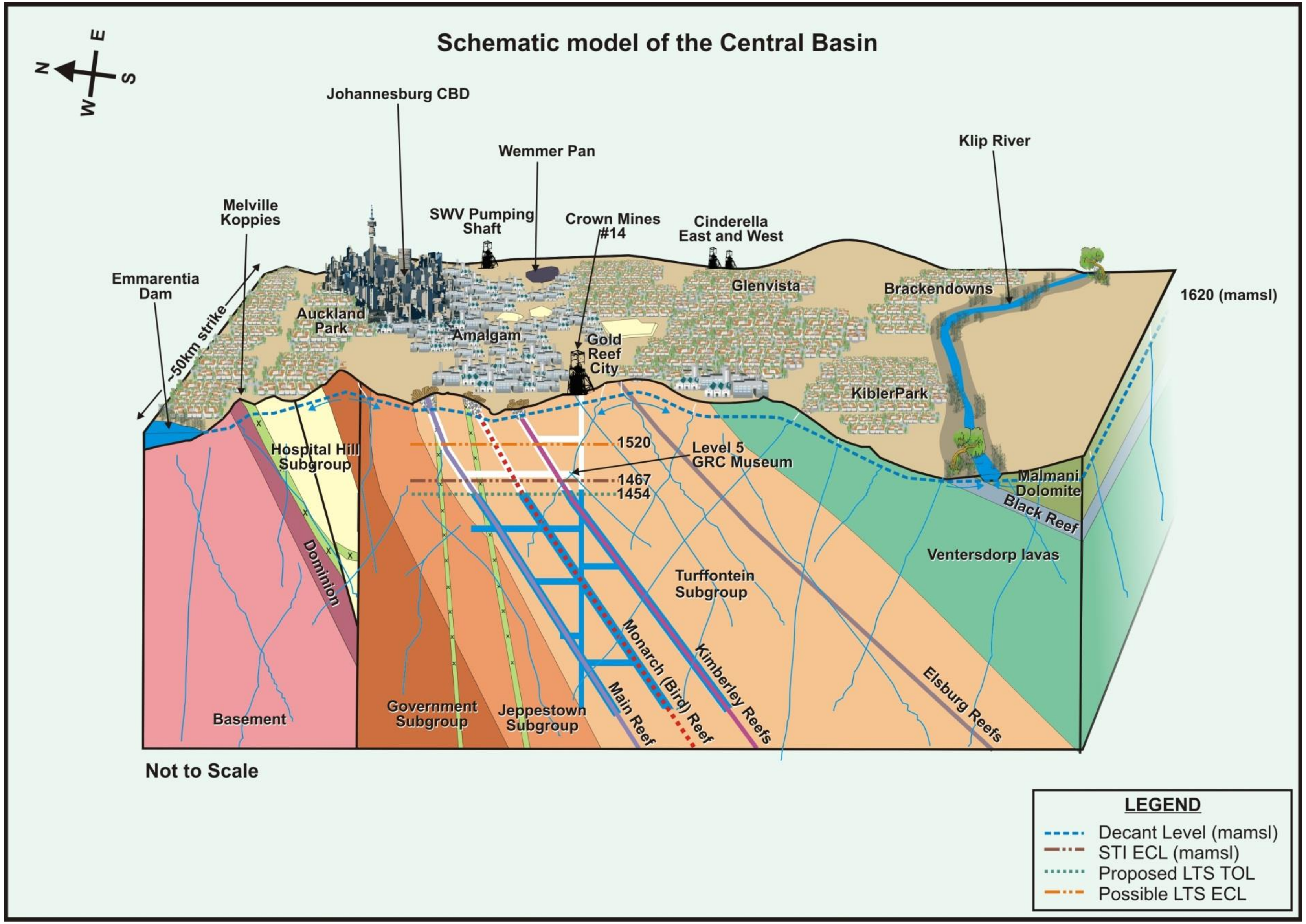


Figure 7.2: Schematic illustration of a conceptual hydrogeological model for the Central Basin

7.3 Mine Voids

7.3.1 History, distribution and connectivity

Mining operations commenced in the Central Basin in 1886 and, over its long history, numerous mining companies were active. Because of increasing depth and higher costs, mines amalgamated, leaving only a few larger players in the field. Starting in the 1950s, these mines began to close, the last two being DRD in 1999 and finally ERPM, which ceased deep level operations in 2008. The impact of this progressive closure of the mines on the extraction of water has been well documented in several reports (e.g. Scott, 1995; Boer *et al*., 2004; Winde *et al*., 2011) and will not be repeated here.

In the Central Basin, the major gold-bearing strata were those of the Main Reef Group (South, Main Reef Leader and Main Reef) and to a much lesser extent the Kimberley Reef (**Figure 7.3**). The Bird Reef was sporadically mined in the west, as was the Ventersdorp Contact Reef (VCR) in the southern Roodepoort area.

The multiple reefs of the Main Reef Group of conglomerates (South, Main, Main Reef Leader and North Reef) progressively converge towards the eastern end of the Central Basin. In the eastern portion of ERPM only a single reef is developed, known as the Composite Reef. This convergence of the reefs coincides with the western flank of an anticlinal structure (the Van Dyk Anticline) which forms part of the Springs Monocline that marks the western limit of the Eastern Basin. In the Eastern Basin, only a single reef, the Nigel or Main Reef, is developed at this stratigraphic level.

The payability of the Composite Reef evidently also declined towards the east and the reef was therefore not mined along the far eastern portion of ERPM, a region known as the Boksburg Gap. To the east of this zone, payability improved and extensive mining took place on the Main Reef in the Eastern Basin. The two areas are separated by a minimum of 500 m of solid rock, which constitutes a substantial pillar (Arnold *et al*., 2005).

By the time the operating mines had dwindled to just DRD and ERPM, it was evident that the mine void could be divided into several discrete sub-basins which were separated by boundary pillars that had been plugged. Once DRD ceased pumping, its void filled and water began to cascade over the boundary pillars towards the last remaining mine in the east (ERPM). This mine ceased pumping in 2008 and the water level in the compartments in the central and eastern regions began to rise. They have now equilibrated and the water level across the basin appears to be rising in unison, with the exception of the Far East Sub-compartment at ERPM, which is described below.

Zones of fairly high payability on the Composite Reef were found to extend in a south-easterly direction. To access the down-dip extensions of this zone of payable gold reef, the Far East Vertical (FEV) Shaft system of ERPM was sunk (**Figure 7.3**). This became a quasi-independent section of ERPM and was connected through to the older mine workings on only a few relatively deep levels. The ore reserves on the older mining areas began to be depleted and the possibility of a cessation of mining and hence pumping was looming. For mining operations at FEV to continue, strategically placed plugs were installed on 68, 58 and 42 levels. These plugs were intended to protect the FEV Shaft operations from flooding when routine pumping from 24 level at South West Vertical (SWV) Shaft ceased. The Far East workings are therefore completely separated from the ERPM Hercules Compartment.

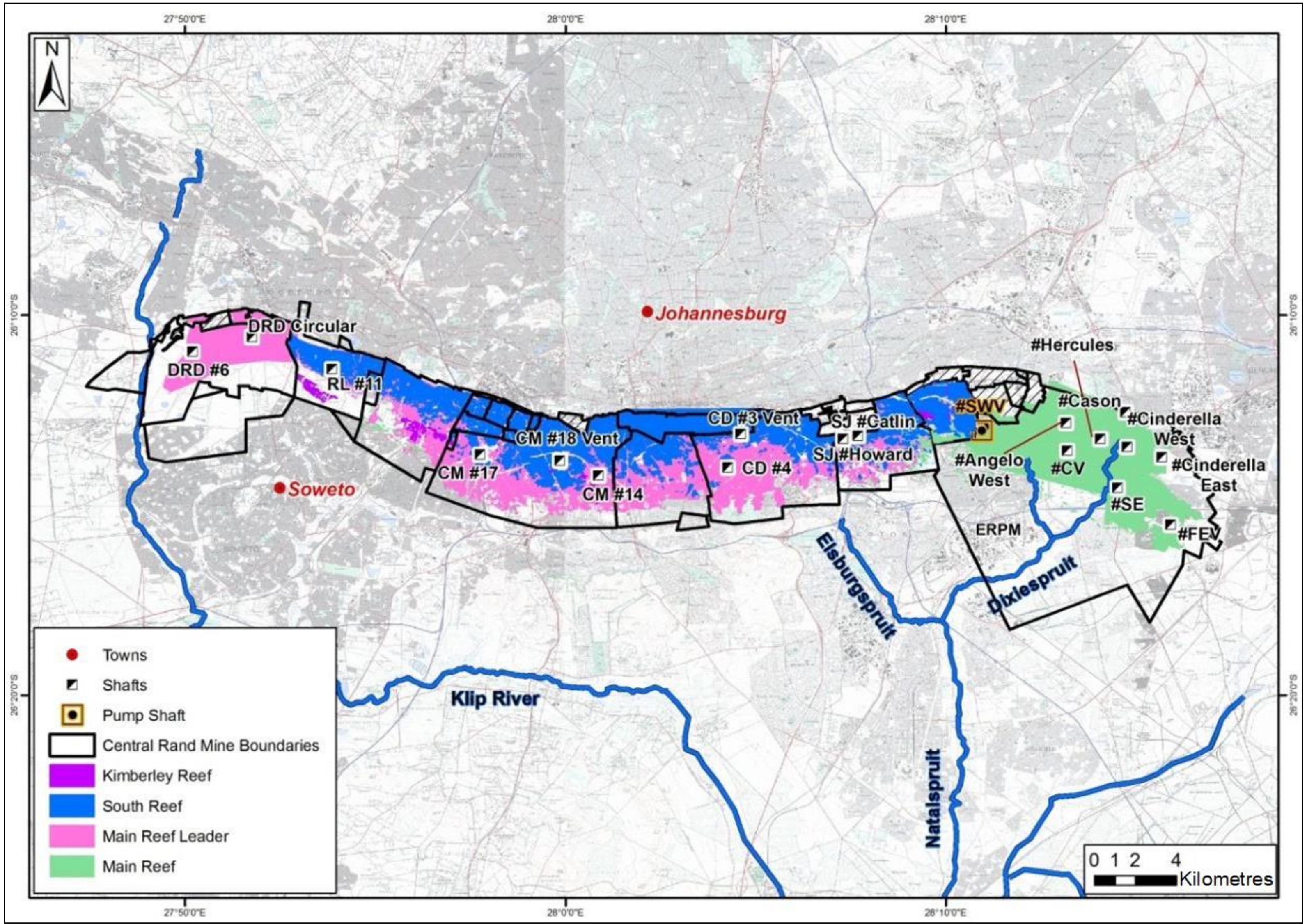
Mining has since ceased in the Far East Sub-compartment and it is now slowly flooding. Since it is apparently no longer connected to the remaining portion of ERPM and ingress is restricted, the rate of rise of the water level in the FEV Shaft is far slower that in the Central Basin as a whole. However, it should be noted that the FEV Shaft collar elevation is one of the lowest in the Central Basin (). Regular monitoring of the water level in this shaft is therefore strongly recommended.

It is assumed that, at the shallower levels that are now filling, there is free and open connection across the mine void from DRD to ERPM (e.g. Winde *et al*., 2011). However, examination of mine plans indicates that the mined out area is transected by numerous large dykes and zones of fault loss where mining was not carried out. These structures were penetrated by haulages, but often these haulages were partially sealed by ventilation doors or even brick walls. The locations and frequency of these barriers is unknown. If present in sufficient numbers they could impede, although not prevent, lateral flow of water through the void. The effect of these obstacles on the flow of water in the void will only become known once pumping commences.

Apart from the main mine void (not investigated in this study) are known isolated pockets of mining that do not contribute to the overall water levels in the main void. However, these pockets will fill up over time and should be investigated as to whether they will decant or not. It is likely that the water levels will reach the water table as cease rising, although this depends on the hydrogeology of the immediate area. It is recommended that a thorough investigation be undertaken to identify all mining pockets. The following are known locations of isolated mining in and around the Central Basin, which can be found in **Appendix B**:

- The Kimberley Reef was mined on CMR without any known connections to other mine voids (number 2 in **Appendix B**);
- The Bird Reef was developed on Crown mines, east of Nasrec Road and south of the railway line. It is not sure whether any stoping was conducted (number 3 in **Appendix B**);
- The Bird Reef may also have been developed or mined east of the M1 between Selby and Booysens (number 4 in **Appendix B**);
- There may have been mining of the Kimberley Reef on City Deep, south of Rosherville Lake. It is not known whether this mining is connected to the main mine void (number 5 in **Appendix B**);

- ERPM Eastern workings, where the crosscuts connecting these workings to the main ERPM infrastructure were plugged. This void is now completely isolated from the Central Basin and will fill separately (number 6 in **Appendix B**);
- Rietfontein Mine, situated in Germiston. Several reefs were mined in this isolated outlier of Central Rand Group rocks (number 7 in **Appendix B**); and
- Orion and Minerva Gold Mines, situated on the Black Reef in the Natalspruit area (number 8 in **Appendix B**).



Note the Main Reef in the ERPM area is a Composite Reef comprising Main Reef Leader and Main Reef. Hashed areas were mined but no void data is currently available

Figure 7.3: Map showing mined out area of the Central Rand

7.3.2 Water levels

The Central Basin is essentially subdivided into three sub-basins or compartments:

- the western DRD-RL (Durban Roodepoort Deep - Rand Leases) sub-compartment;
- the central CMR-SJ sub-compartment (Consolidated Main Reef - Simmer & Jack); and
- the East Rand Proprietary Mines (ERPM) sub-compartment (Rison, 2001).

Figure 7.4 schematically illustrates the compartmentalisation of the Central Basin and shows key shaft, haulage and plug positions (note that the water level shown is for 2001, after pumping ceased at DRD but prior to cessation of pumping at ERPM). The historic water flow and management in the Central Basin is illustrated in **Table 7.1**. East of the main ERPM compartment is the Far East Sub-compartment, which is isolated by plugs from the rest of the Central Basin.

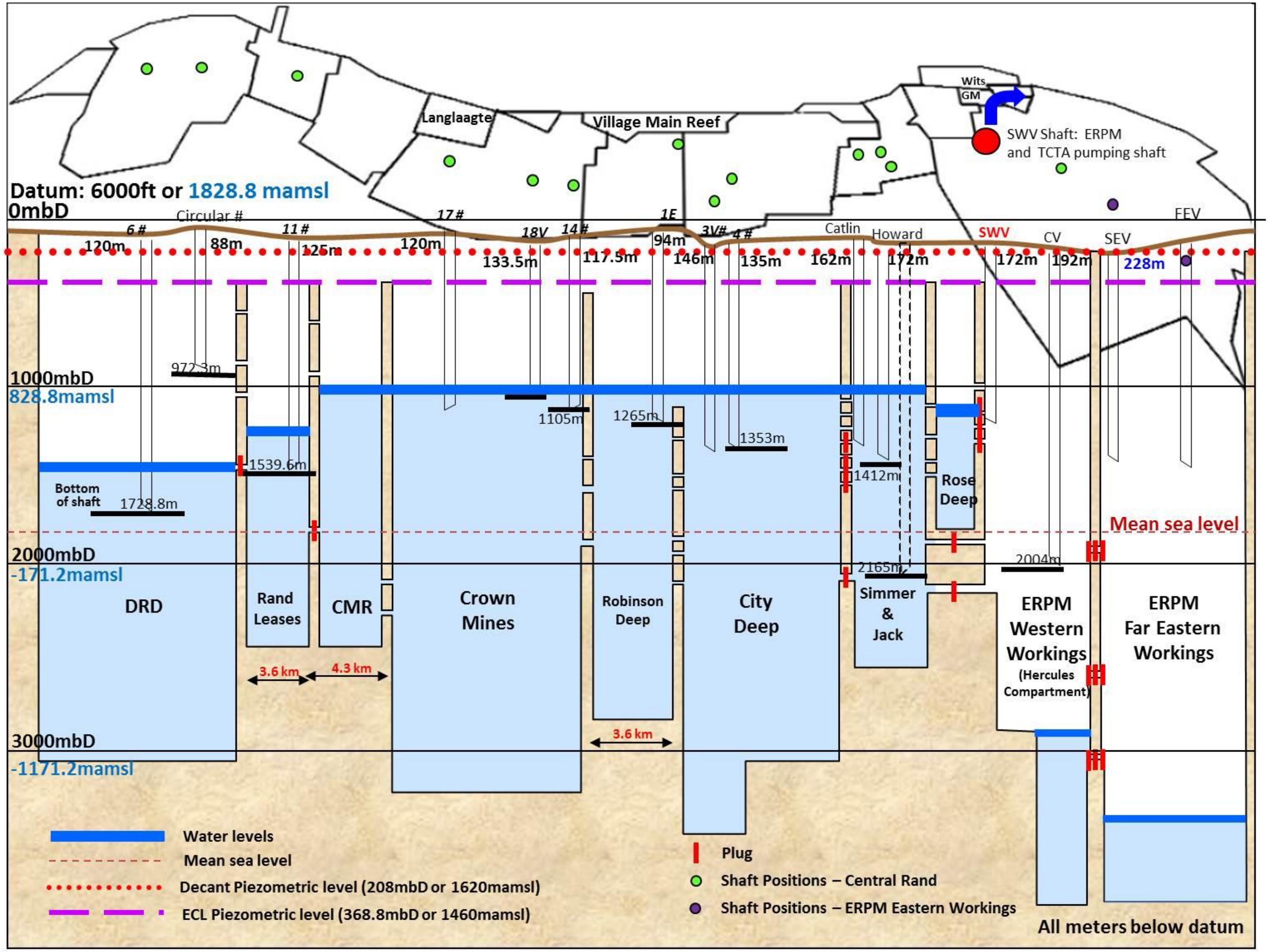


Figure 7.4: Sub-compartments in the Central Basin mine void (note water levels as per 2001)

Table 7.1: Historic water flow (Mℓ/d) and management in the Central Basin

Year	DRD_5	RL	CMR	CM	RoD	CD	SJ	RsD	ERPM _Herc	ERPM _SWV
1952	4.9	3.7	7.1	7.4	4.4	7.4	4.4	4.5	10.4	
1953	6	4.3	6.4	7.6	4	8.6	3.8	5.1	10.2	
1954	6.1	3.1	7.6	7.1	3.6	8.2	4	4.4	11.6	
1955	7.9	6.1	6.6	10	4.4	10.1	5.2	5.6	12.7	
1956	7.4	4.3	6	9.2	4.5	9.6	4.1	5.4	11.6	
1957	7	4.4	8.1	9.4	4.8	9.3	4.3	5.9	11.9	
1958	5.7	5.2	5.8	8.7	4.4	7.1	4.4	5.6	12.3	
1959	7.3	3.2	6.8	8.2	4.3	6.8	4.1	3.3	11.9	
1960	nr	nr	nr	nr	nr	nr	nr	nr	12.9	
1961	nr	nr	nr	nr	nr	nr	nr	nr	12.5	
1962	nr	nr	nr	nr	nr	nr	nr	nr	11.2	
1963	nr	nr	nr	nr	nr	nr	nr	nr	10.2	
1964	nr	nr	nr	nr	nr	nr	Closure	nr	11.9	
1965	nr	nr	nr	nr	nr	nr		Closure	nr	
1966	nr	nr	nr	nr	Closure	nr			nr	
1967	nr	nr	nr	nr		nr			nr	
1968	nr	nr	nr	nr		nr			6.9	
1969	nr	nr	nr	nr		nr			17.6	
1970	nr	nr	nr	nr		nr			19.7	
1971	nr	Closure	nr	nr		nr			21.4	
1972	8.1		nr	nr		nr			19.6	
1973	8.3		nr	nr		nr			14.2	
1974	9.6		nr	nr		nr			18.3	
1975	11.5		Closure	nr		nr			nr	
1976	18.9			nr		Closure			16.2	
1977	18.7			Closure					12.7	33.2
1978	21.6								13.9	33.4
1979	16.9								14.6	23
1980	17.2								17.5	27.8
1981	17.9								18.4	29
1982	17.1								17.9	25.9
1983	15.8								17.9	24.6
1984	16								18.8	22.2
1985	nr								nr	nr
1986	14.3								19.1	25.6
1987	17								20.9	33.7
1988	21.4								nr	28.9
1989	nr								18.4	26.8
1990	19.2								17.8	19.9
1991	nr								nr	37.6
1992	nr								nr	37.5
1993	nr								nr	39.6
1994	22.4								nr	42.7
1995	18.1								16	31.1
1996	17								nr	nr
1997	18								18	16.2
1998	nr								44.8	
1999	stopped								nr	
2000									nr	nr
2001									16.4	33.4
2002									15.2	36.3
2003									15.5	38.5
2004									stopped	35
2005										
2006										41.3
2007										39.7
2008										54.1
Oct-2008										stopped

Notes: DRD – Durban Roodepoort Deep; RL – Rand Leases; CMR – Consolidated Main Reef; CM – Crown Mines; RoD – Robinson Deep; CD – City Deep; SJ – Simmer and Jack; RsD – Rose deep; ERPM – East Rand Proprietary Mines Limited; nr – no record.

The available mine water level data for the Central Basin are presented in **Figure 7.5**. This diagram is based on multiple datasets (L du Plessis, Gold Reef City, pers. comm., 2012; H Coetzee, CGS, pers. comm., 2012; V Labuschagne, ERPM, pers. comm., 2012), and illustrates the gradual decrease in the filling rate (m/d) as successive compartments merged and the volume of the void increases. The decrease may also in part be due to the gradual reduction in the hydraulic gradient. The merging of the CMR-SJ sub-compartment (green arrow in **Figure 7.5**) with the ERPM sub-compartment at about 820 m amsl reduced the rate of filling (lowering in the slope of the black arrows). The same effect is observed when the DRD-RL sub-compartment (blue arrow) equalised at 1 049 m amsl with the larger CM-ERPM basin.

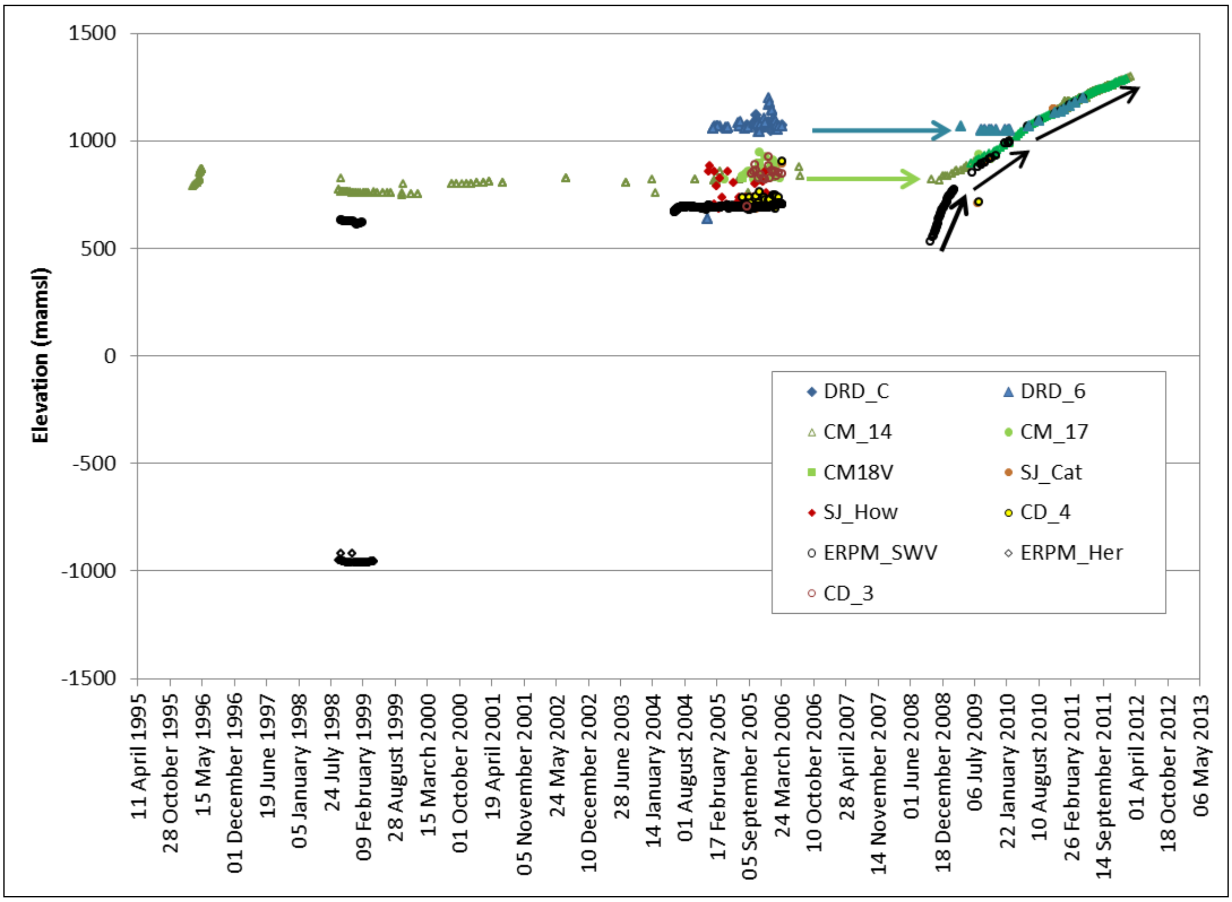


Figure 7.5: Historic mine water level pattern and trend (rise and filling) of the Central Basin

7.3.3 Predicted decant

The elevation of the outcrop of the Main Reef essentially decreases from west to east and the lowest points accessing the mine void occur at ERPM in the east. The TCTA (2011) study identified Cinderella East Shaft as the expected surface decant site at an elevation of 1 617 m amsl. This study, however, indicates that shafts with the lowest collar elevations accessing the mine void and that have not been subsequently filled, are Cinderella East (1 627 m amsl) and Cinderella West (1 621 m amsl). These elevations are based on Google Earth elevations, since Winde *et al*. (2011) found that in open terrain such as the mining belt, this data closely matched the surveyed shaft collar elevations, with an average deviation of only 0.2 m. Other ERPM Shafts which have similar elevations are also potential surface decant sites, even though they have been filled with rubble. These include the Hercules (1 621 m amsl), Angelo West (Vent; 1 620 m amsl), Angelo Deep (1 629 m amsl) and Central Vertical (1 639 m amsl) Shafts.

Decanting on surface, if allowed to occur, will take place at one or more of these shafts, or possibly at points where fractures connected to the mine void allow water to escape at a lower elevation (**Figure 7.6**).

Winde *et al*. (2011) undertook an investigation of the Central Rand surface decant locations, and more detail can be obtained from that report. The Winde *et al*. (2011) study identified Cinderella West at 1 613.7 m amsl as the shaft with the lowest elevation. However, the LTF study has found that Cinderella Dam is located at this elevation, and ERPM survey data place Cinderella West Shaft at 1 625 m amsl, or 1 621 m amsl according to Google Earth. The DWA is currently in the process of re-surveying all of the key shafts in this area, which should provide the definitive collar elevation data that is critically needed.

The final merging at 1 049 m amsl of the mine water levels in all three compartments of the Central Basin occurred in May 2010, demonstrating connectivity across the basin. New data allow a revised prediction of the surface decant and ECL dates (**Figure 7.7**). Keeping in mind the risks of excessive extrapolation, the current estimate for the water levels in the Crown Mines 14 Shaft to reach the ECL proposed by TCTA (1 467 m amsl) is estimated at ca. January 2014, with surface decant sometime in 2015. This contrasts with the TCTA original estimate of August 2012 for breaching the ECL. Water levels as measured in the Crown Mines 14 Shaft rose at a rate of 0.3 to 0.4 m/d during February 2012, and although somewhat tenuous, appear to show a small decreasing trend with time (**Figure 7.8**).

If the mine water was allowed to rise and decant on or very near surface, there would be contamination of significant areas of shallow aquifers and the objective set by the IMC of protecting these groundwater resources would not be met. It is therefore necessary to set an ECL.

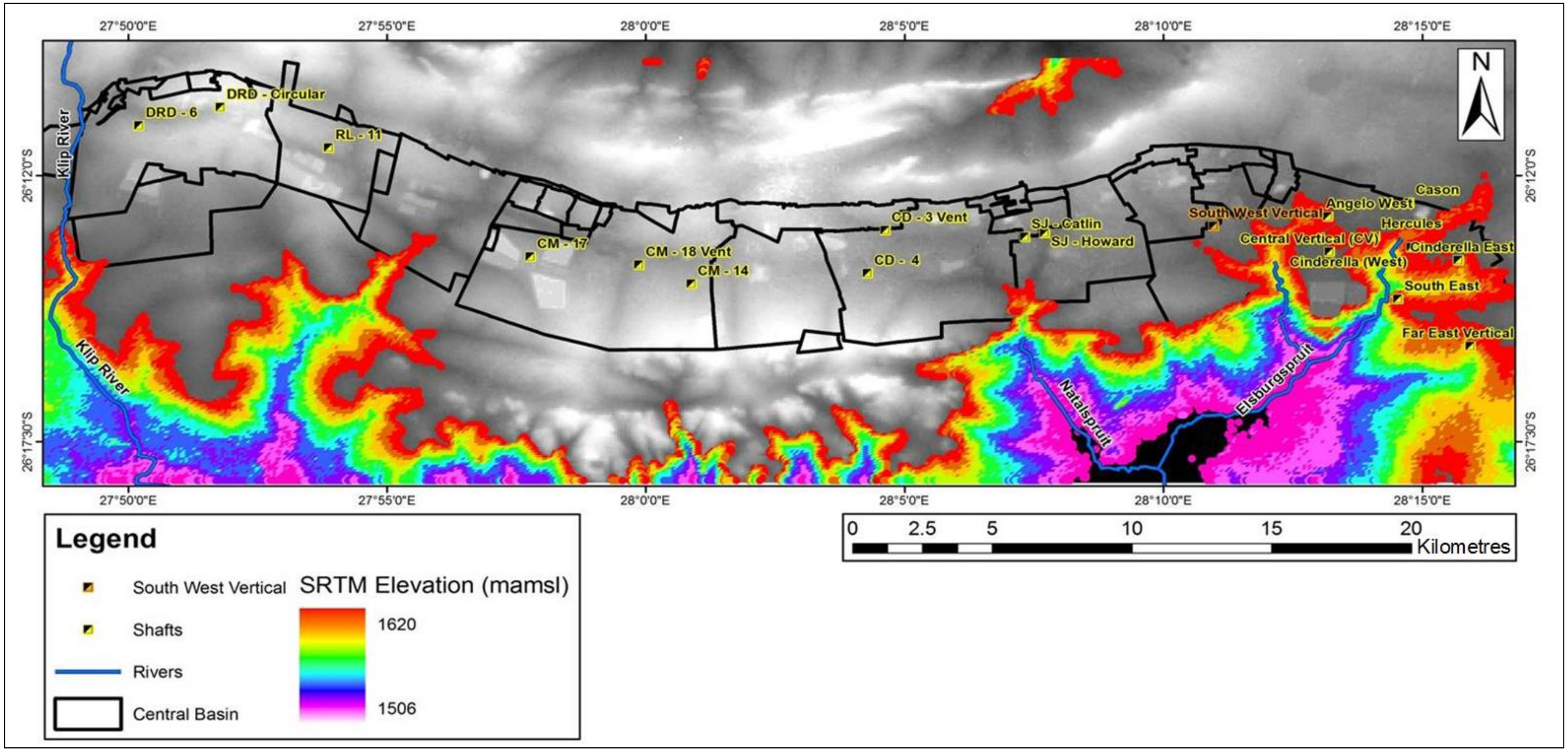


Figure 7.6: Elevations in the Central Rand below 1 620 m amsl defined by Shuttle Radar Topography Mission (SRTM) data

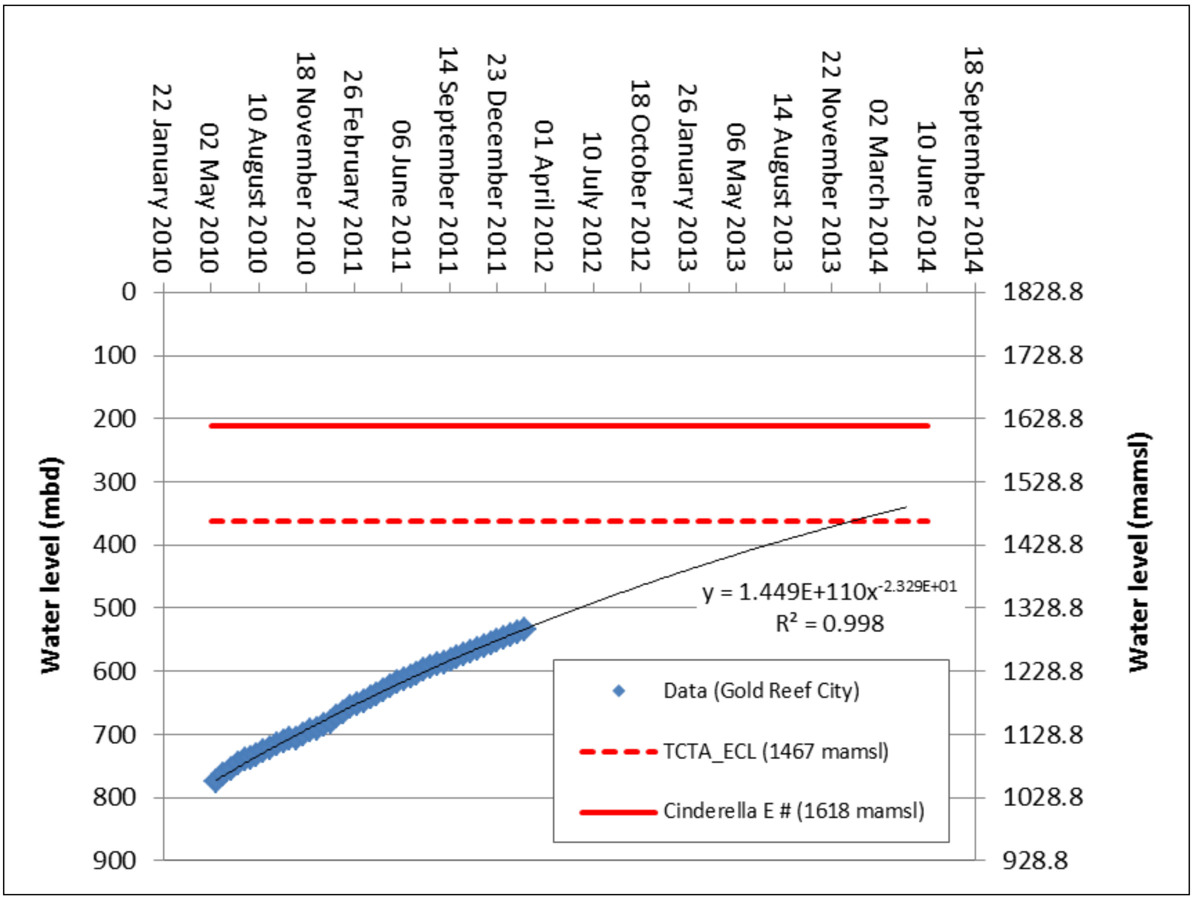


Figure 7.7: Predicted surface decant and ECL dates for the Central Basin

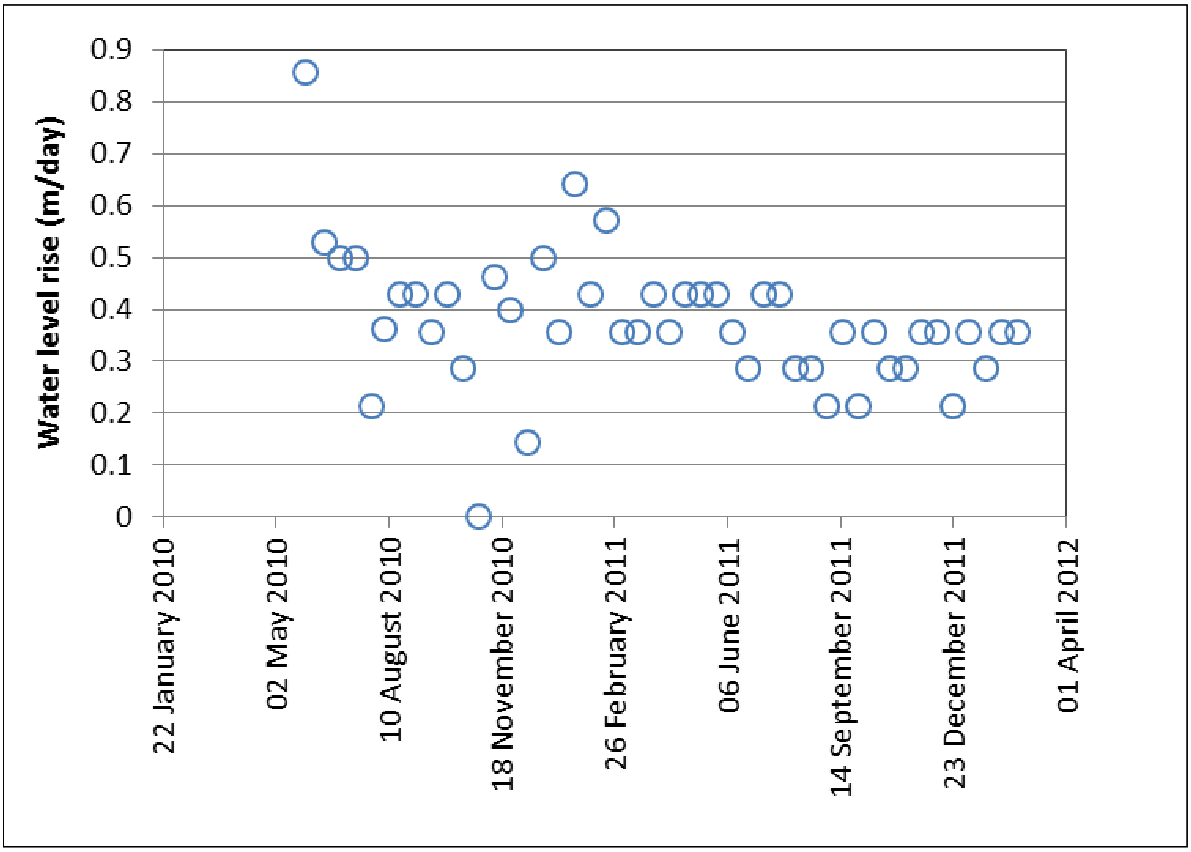


Figure 7.8: Pattern and trend of mine water level rise in the Central Basin

7.4 Critical Water Levels

7.4.1 Proposed Environmental Critical Level

The TCTA (2011) proposed ECL of 1 467 m amsl, at a depth of 150 m below a postulated surface decant elevation of 1 617 m amsl at ERPM, targeted the protection of groundwater resources. The ECL was designed to accommodate a 50 m buffer (TOL) with the shallow weathered and fractured aquifer only considered to extend to '80-100 m below the surface' (Annexure B of TCTA, 2011). **Figure 7.9** indicates the inferred consequences of allowing the mine water to rise to decant, flowing into the weathered rock aquifer and into the base flow of the streams.

Available borehole data indicates a generally shallow depth (typically <20 m) to natural groundwater level in the Central Basin region. This study proposes an ECL of 1 520 m amsl (**Figure 7.10**) based on an estimated depth of 100 m below the potential surface decant elevation at ERPM (**Section 7.3.3**). This should adequately protect the shallow weathered aquifer and the streams in the area. The ECL proposed by this study does not incorporate a substantial 'buffer' such as was considered in the TCTA (2011) study, as this will be reflected in the definition of a static water level in the Technical Prefeasibility Report (DWA AMD FS 2012, Study Report No. 5).

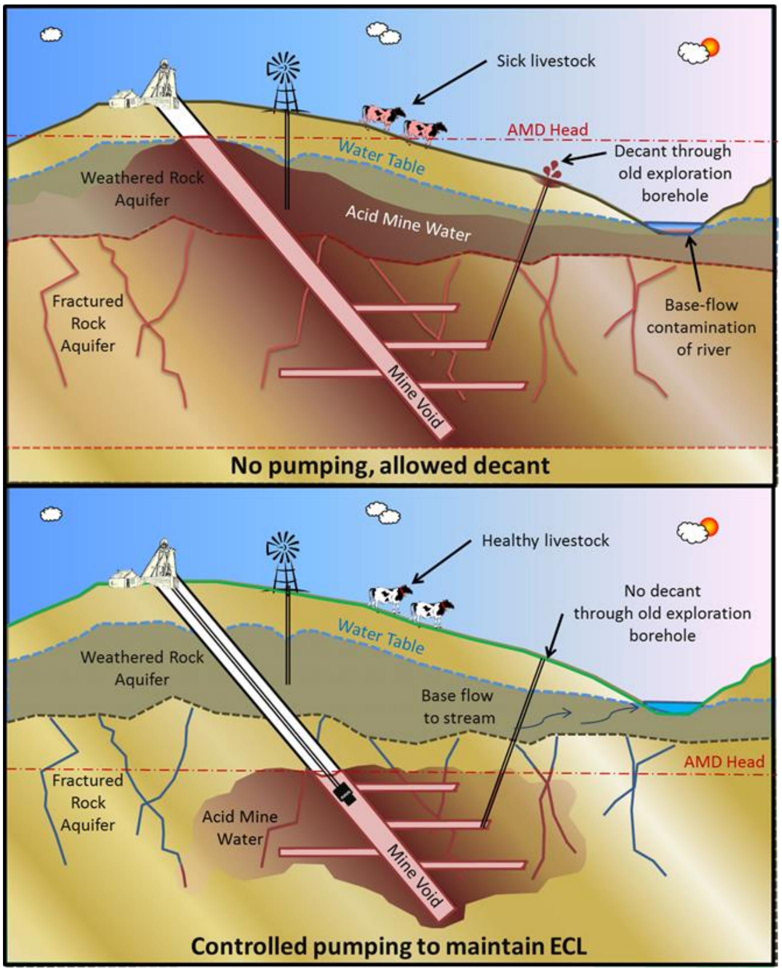
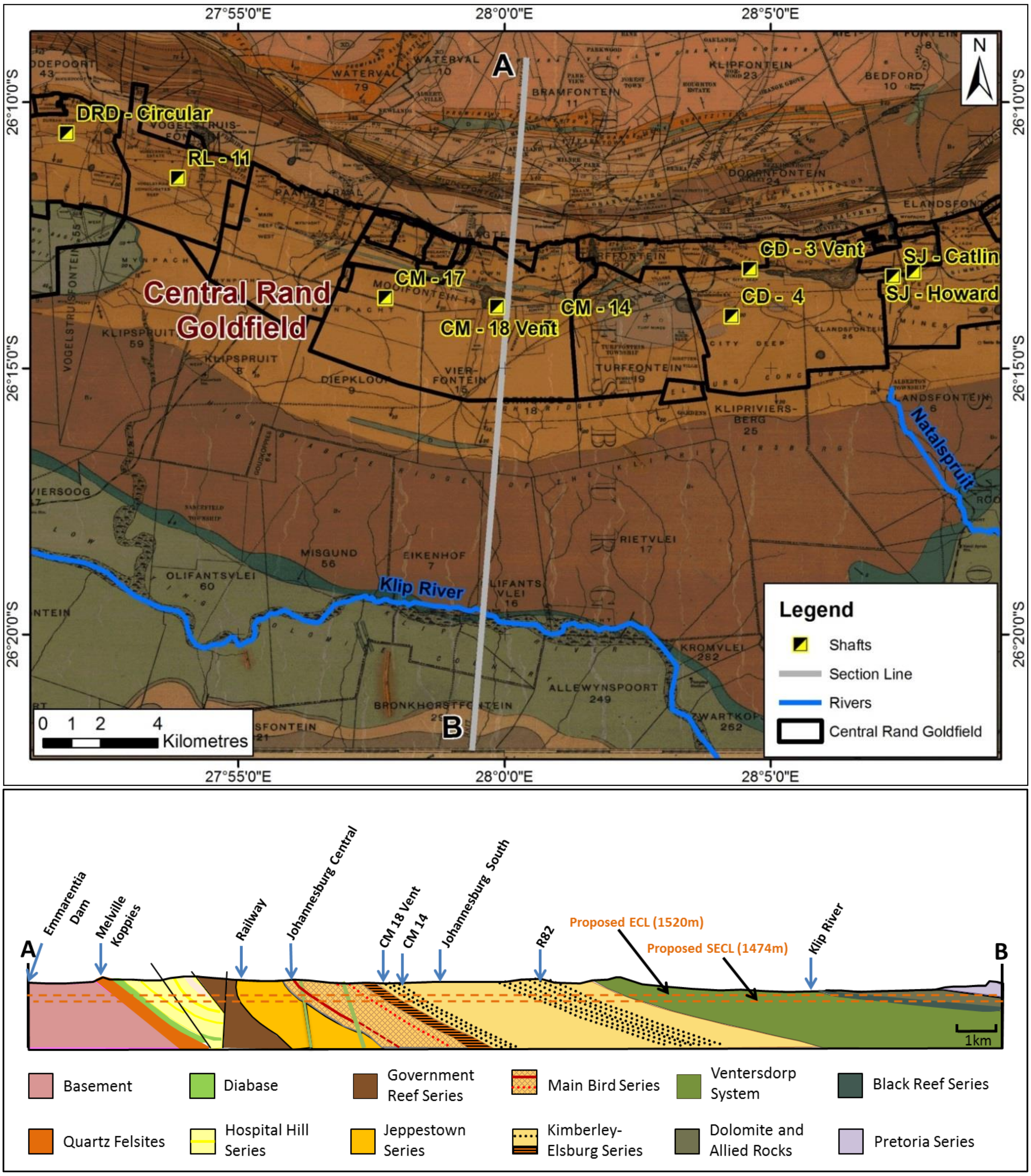


Figure 7.9: Illustration of the effect of allowing decant or implementing the suggested

A program of drilling across the Central Basin is recommended to improve definition of the depths of the shallow aquifer especially in proximity to and overlying the zone of shallower mining activity. This will enable a more accurate elevation to be set for the ECL.



Cross-section shows ECL as proposed by the TCTA (2011), and the ECL/SECL as proposed by this study.

Figure 7.10: Geological map of the Central Basin, with a cross-section along the centre-line

7.4.2 Proposed Socio-Economic Critical Level

The IMC set the ECL (re-defined as the SECL) at 1 503 m amsl in the Central Basin so as to protect the historic underground mining museum in Crown Mines No. 14 Shaft (CM14) at Gold Reef City (GRC). The socio-economic imperative of such an ECL re-defines it as an SECL. The TCTA (2011) ECL of 1 467 m amsl would also serve this purpose.

Based on the latest available survey data from the DWA, the collar elevation of CM14 has been definitively set at 1 699 m amsl (E van Wyk, pers. comm.). According to several sources, including historic mine plans and sections, the 5 Level museum historic mine workings are at 215 m below surface (1 484 m amsl). To protect 5 Level and allowing additional space for the double-decker conveyance and minor errors in elevation/depth data, an SECL of 1 474 m amsl is proposed (**Figure 7.10**).

Figure 7.11 illustrates the location of the TCTA (2011) ECL and this study's proposed SECL in the form of a north-south cross-section through CM14 Shaft and workings. It should be noted that Gold Reef City management are conducting detailed contingency investigations into the relocation of the mining museum facility to 2 Level, 75 m below surface (1 624 m amsl). Whilst this would be suitably protected at the proposed ECL of 1 520 m amsl (**Section 7.4.1**), it would offer very little freeboard in the event of natural decant at approximately 1 620 m amsl. It should also be noted that 5 Level was once an active working level on the mine, enhancing its candidacy for preservation. Redevelopment would require the excavation of new tunnels from the shaft to the Kimberley Reef stopes, and would in a sense be artificial. If at all possible, the actual spaces where miners spent their working days should be preserved for posterity.

Should the proposed shallower ECL of 1 520 m amsl be applied in the Central Basin, it may be possible to retain the museum facility on 5 Level by plugging CM14 Shaft. Pumping facilities would also have to be installed. Any other voids that connect the Kimberley Reef workings with the Main Reef workings on the mine would also have to be sealed. The water level is currently at 1 330 m amsl (as of 13 July 2012: L. du Preez, pers. comm.) and therefore close to submerging 8 Level (at approximately 1 340 m amsl). At these rising water levels, plugging may be a very challenging operation due to the multiple connection points at 5 Level with the flooded workings below (**Figure 7.12** – Numbers indicate mining levels; yellow indicates CM14 Shaft and 5 Level museum facility). Failure of a plug could have catastrophic consequences, and public perception may be such that this would not be a viable solution even if technically feasible.

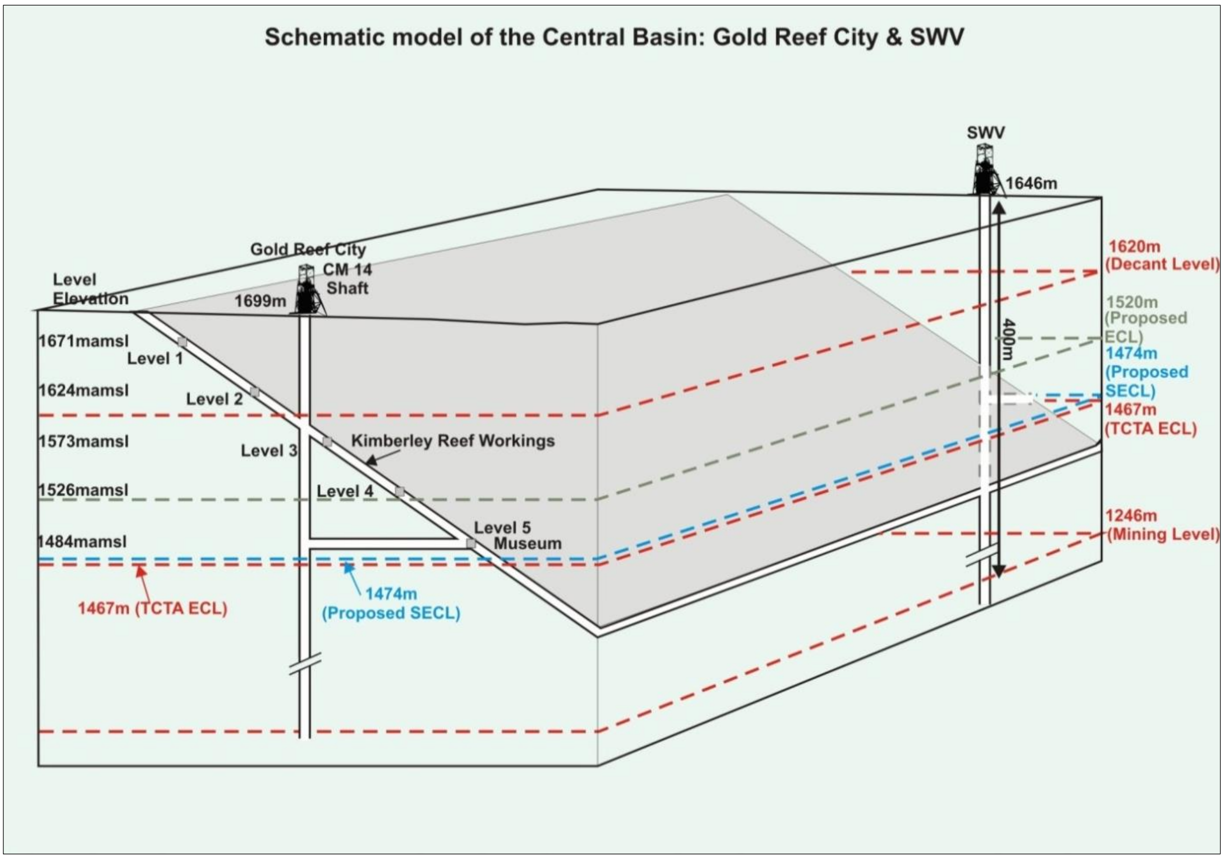


Figure 7.11: Schematic cross-section of CM14 Shaft

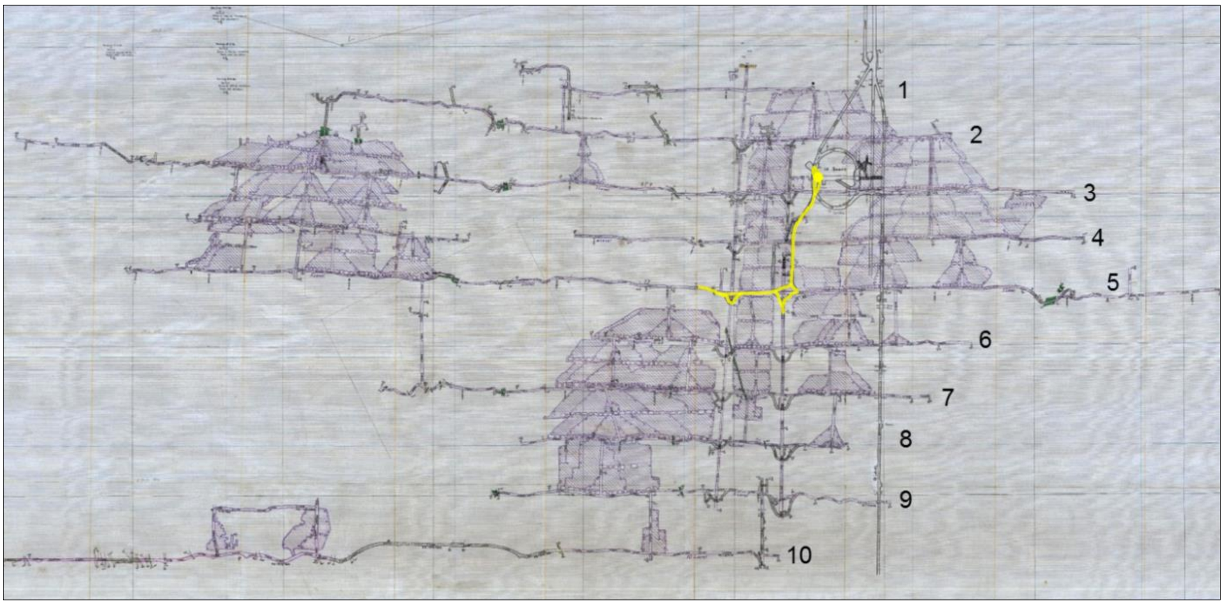


Figure 7.12: Crown Mines Kimberley Reef mine plan

7.5 Surface Water Ingress

Streams in the Central Basin originate in the E-W striking unmined ridges of the West Rand Group of the Witwatersrand ridges and drain southwards towards the Vaal River. The Klip River and Klipspruit drain the western portion of the Central Basin. The central portion is drained by the Natal Spruit, and the eastern portion by the Elsburgspruit.

The land use in the immediate vicinity of the study area consists primarily of urban development. This includes commercial, industrial and residential development, with the city of Johannesburg being the most prominent urban feature. The built-up areas are mainly concentrated to the north of the outcrop of the gold-bearing reefs. The surface excavation of the shallow reefs along their outcrop, with a strike length of approximately 15 km, resulted in a band of topographically lower lying areas with highly disturbed land coverage, allowing a higher rate of infiltration of precipitation. Land use to the south of this band comprises predominantly agricultural land for grazing and maize crop production. It should also be noted that rainfall runoff in this basin has a fairly low effect on the ingress volumes because of the already constant flow in the watercourses from leaking sewer lines and stormwater drainage systems.

For each of the ingress sources described in **Section 4.3**, a percentage of recharge (ingress) of rainfall and surface water runoff was estimated taking into account the existing geological formations as well as potential ingress sources as listed above, to predict the expected ingress volumes into the mine workings. In addition, relevant and applicable rainfall records needed to be compiled before being able to determine the ingress volumes.

7.5.1 Meteorology

The major source of inflow to the basin is rainfall onto open mine workings, as well as runoff from catchments draining into the mine areas. Several rainfall stations in the greater Johannesburg area have been used to determine the average, minimum and maximum monthly rainfall in the basin. The WUC (2009) study provided this study with the most up to date information. The extracted monthly average rainfall data are presented in **Table 7.2** and the annual minimum and maximum rainfall in **Table 7.3**.

In addition to the WUC (2009) analysis, an independent assessment of the average monthly rainfall as well as minimum and maximum monthly rainfall has been carried out as part of this study. Two stations, namely 0475881W with 98 years of record and 0476012W with 63 years of record (**Figure 4.3**), were used for this. The average monthly rainfall of the two stations is presented in **Table 7.4**.

The following observations derive from a comparison of the rainfall datasets:

- The reviewed MAP (783 mm) is similar to the 733 mm of the WUC (2009) study, albeit about 6% higher;
- The maximum monthly reviewed rainfall (470 mm in April 1908) is 39% higher than the WUC (2009) value of 338 mm (March 1998). This could possibly be due to a more

accurate and patched rainfall record used for the review study, which is based on the rainfall database used by DWA for all resource modelling (Middleton and Bailey, 2005); and

- It is noted from **Figure 4.3** that the expected average rainfall could increase by about 40% over the Gauteng region due to climate change. Given the short length of the rainfall record used, in terms of meteorological time scales, the potential impact of climate change should still be taken into consideration in any further predictive studies of ingress.

Table 7.2: Monthly rainfall figures in the Central Basin (WUC, 2009)

Month	Average Rainfall (mm)	Minimum Rainfall (mm)	Year Recorded	Maximum Rainfall (mm)	Year Recorded
October	73.59	13.47	1999	200.5	2001
November	112.2	8.3	1951	214.95	1998
December	118.34	45.45	1984	265.15	1949
January	131.86	42.53	1956	314.35	1978
February	101.28	21.75	2007	281.7	2000
March	88.45	15.5	1966	337.68	1997
April	48.32	2.16	1991	126.34	1990
May	17.26	0	Often	83.9	1997
June	7.29	0	Often	50.47	1963
July	4.87	0	Often	65.33	1957
August	6.55	0	Often	58	1979
September	22.79	0	1953;2008	148.44	1987
Total	**732.8**				

Table 7.3: Annual minimum and maximum rainfall figures in the Central Basin

Month	Driest Year - 1984 (mm)	Wettest Year - 2000 (mm)
October	79.7	98.7
November	100.18	111.6
December	45.45	124.15
January	60.2	148.03
February	22.5	281.7
March	82.25	185
April	9.08	22
May	1.83	22.53
June	8.53	1.33
July	15.2	0
August	0.58	2.4
September	11.55	27.48
Total	**437.05**	**1 024.92**

Source: WUC, 2009

Table 7.4: Average monthly rainfall for the independent review rainfall stations

Month	Average Rainfall (mm)	Minimum Rainfall (mm)	Year Recorded	Maximum Rainfall (mm)	Year Recorded
October	18	0	1977	87	1942
November	18	0	1953	131	1917
December	24	0	1974	106	1956
January	65	7	1940	264	1993
February	116	11	1941	451	1917
March	125	17	1948	275	1949
April	130	20	1942	470	1908
May	110	17	1962	464	1943
June	93	10	1903	258	1996
July	48	1	1938	194	1902
August	23	1	1912, 1946	124	1935
September	12	0	1967	82	1943
Total	**782**				

7.5.2 Review and verification of ingress volumes

An important component of this study is the review and validation, where possible, of the expected ingress of surface water into the mine workings. This has a marked influence on the abstraction requirements and hence pumping and maintenance costs. The following two approaches have been adopted in verifying the predicted ingress volumes:

- Determination of the total ingress into the mine void based on surface flow rates and assumptions on the percentage infiltration of surface water into the mine void from various geological formations, mine infrastructure and natural drainage systems; and
- Determination of the total ingress into the mine void based on mine void volume, water level and pumping data described in **Section 7.5.3**.

a) Sources of ingress and estimated volumes

A summary of ingress areas based on estimates from different surface sources in the Central Basin is given in **Table 7.5** and shown in **Figure 7.13**. Relevant data and assumptions abstracted from the WUC (2009) study, together with flow monitoring data, yield the predicted ingress volume of 59 Mℓ/d reported in **Table 7.6**. The approximate percentage distribution of each of the sources is also given in **Table 7.6**.

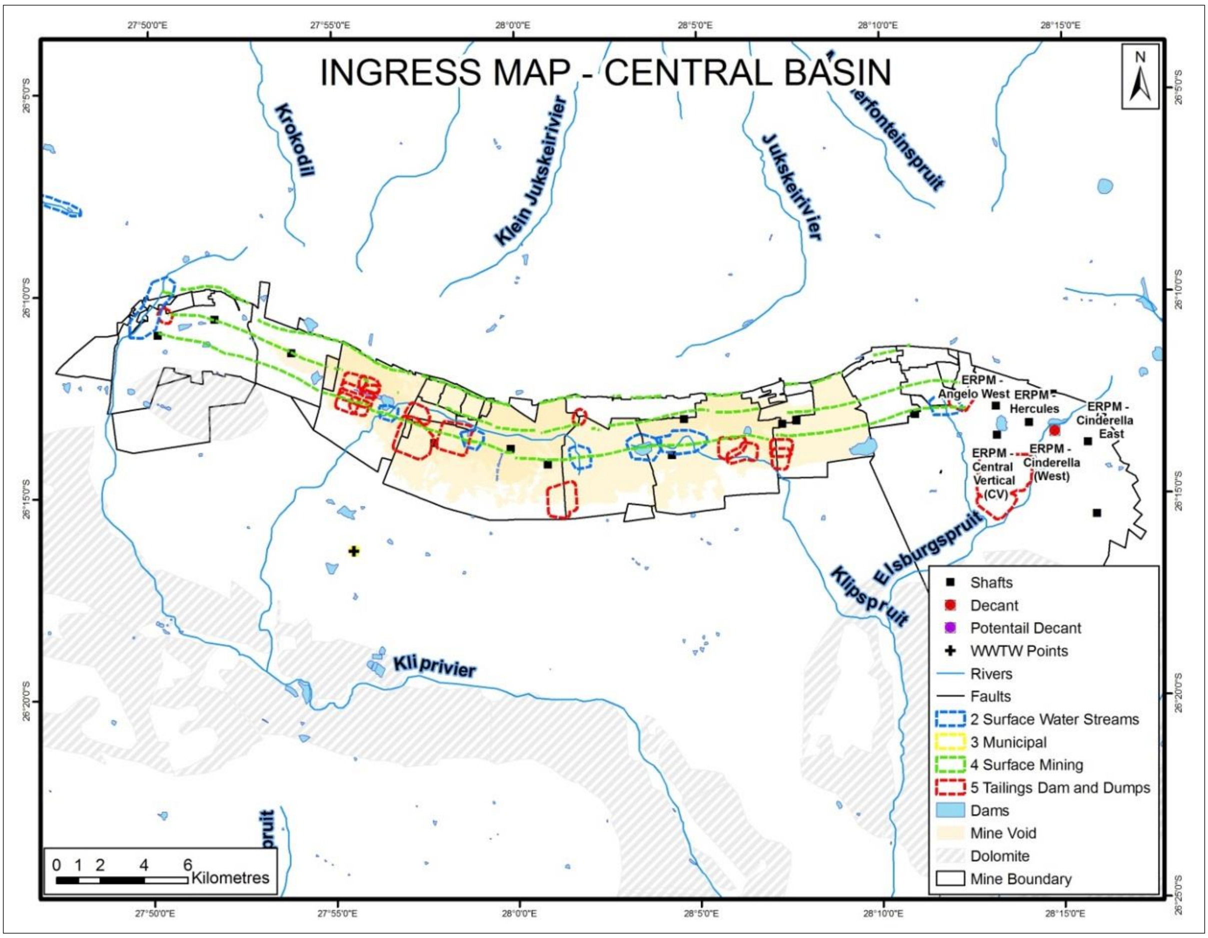
Table 7.5: Summary of ingress areas

No.	Ingress Area	Comments
1	Undisturbed geology /Shallow aquifers	Ingress through the shallow aquifer above the mine void has been estimated as between 69% to 40% of total ingress by different reports (Winde *et al*., 2011). However, as no dolomite aquifers overlie the mine void and extensive urbanisation reduces recharge of shallow aquifers, this estimate is considered to be too high.
2	Surface water (dams, rivers, wetlands)	Water discharged to the Elsburgspruit and Boksburg Canal could ingress to the mine void where surface streams and tributaries of the upper reaches of the Klipspruit cross undermined areas or structures such as dykes, faults as it flows parallel to strike (E to W) over the void. Ingress from streams has been estimated to account for 26.7% to 40.4% of the total ingress by Winde *et al* (2011).
3	Municipal infrastructure (leaking mains and sewerage, stormwater runoff)	The Central Basin is highly urbanised (Johannesburg and Ekurhuleni Municipalities) so a larger component of water leaking from municipal services adds to the volume of water entering the mine void. In addition, irrigation of mine golf courses, vegetated slimes dams etc., adds to sub-surface seepage.
4	Surface mine workings (open pits, shafts, inclines)	Extensive historic pits along the strike of the Central Basin have been poorly back-filled, allowing high infiltration varying from 1.2 to 12.5 Mℓ/d (4 to 14% of total ingress) into the void according to different studies.
5	Tailings dams and mine dumps	Ingress of water from mine residue deposits (at least 15 identified) which were placed directly on top of disturbed reef, over shafts, or on dykes or faults connected to the void. There are reports of tailings pumped directly into the mine void resulting in an ingress of >3.5 Mℓ/d although this practice has been discontinued (Winde *et al*., 2011). Reclamation of mine dumps results in active disposal at 3 existing slimes dams at Nasrec with estimated 10 Mℓ/d seepage losses. Seepage rate of 7 Mℓ/d estimated from Cooke slimes dams (Winde *et al*., 2011). Water used to hydraulically mine the dumps is also a source of ingress, but this will reduce once the dumps have been removed.

Table 7.6: Predicted ingress volumes and sources (average rainfall)

Source	Percentage of Total Ingress Volume	Ingress Volume (Mℓ/d)
Groundwater recharge via undisturbed geology	41	24
Ingress through reef outcrops	11	7
Underground disposal of tailings	4	2
Sand dumps	0	0
Shallow perched aquifers above mine void	30	18
Ingress from rivers, drainage systems & water bodies	14	8
TOTAL	**100**	**59**

Source: WUC, 2009



Note: Numbers in legend refer to source type in the preceding table

Figure 7.13: Major ingress areas in the Central Basin

In order to assess the impact of climate change on ingress volumes, the changes in rainfall reported in **Table 7.7** have been used in the predictive Goldsim Model utilised by Golder & Associates for the WUC (2009) study. The results (**Table 7.7**) indicate a significant impact. For an average change in MAP of 40%, the predicted ingress volume increases by 12%. The potential change in MAP of 20 to 40% due to climate change could increase the ingress volume by as much as 7 Mℓ/d.

Table 7.7: Rainfall variation impact on ingress volume

Rainfall	MAP (mm)	Change in MAP (%)	Predicted Ingress (Mℓ/d)	Change in Ingress (%)
Average	732	0.00	59	0.00
Dry Season	437	-40.30	34	-42.37
Wet Season	1 025	40.03	66	11.86
Extremely Wet	1 413	193.31	73	24
Climate Change	1 025	40.00	66.00	11.86

7.5.3 Estimations based on pumping rates and void volume

Water ingress into the mine void has been the focus of a number of studies, notably those of Scott (1995), Krige (2001) and Boer *et al*. (2004). An important source is rain water and local runoff entering via the disturbed zone in the vicinity of the outcrop. A second source is inflow from streams that cross the disturbed zone. The strike of the reef outcrops run more or less parallel to the watershed and hence there are several streams that cross the outcrop zone. Because of the proximity of the outcrop to the watershed, stream discharge is small and many of the streams are seasonal, carrying most of their annual discharge in short duration storm events. However, sustained flow does occur in several streams due to anthropogenic activity.

Notwithstanding the existence of an extensive mine void across the Witwatersrand, the shallow groundwater aquifer remains relatively undisturbed across the region. In the Johannesburg area, the depth to the water table in this aquifer varies from 0.5 m to about 30 m (Scott, 1995). Some of the water in this aquifer is highly contaminated by plumes that arise from tailings dumps (e.g. Naicker *et al*., 2002). It is likely that in the vicinity of the disturbed zone, water from this aquifer discharges into the mine void. Finally, water also enters the mine void at depth due to depressurisation via water-bearing structures which are linked through to the shallow aquifer above.

At the time of the Scott (1995) investigation, both DRD and ERPM were in operation and gave access to a large amount of data from these sources (2 and 12 years of record, respectively). At ERPM the pumping situation was rather complex and involved extracting water from two separate compartments. The first of these involved water pumped from the Hercules Compartment where mining was still taking place. The total volume pumped averaged 16.02 Mℓ/d, of which 8.93 Mℓ/d was service water provided by Rand Water, with extraneous inflow (including so-called fissure water) contributing the balance of 7.09 Mℓ/d. The second source of pumped water represented inflow from the defunct mines to the west of ERPM (CMR to Rose Deep). The volume of this water amounted to 13.84 Mℓ/d (Scott allowed for some return flow from tailings that were being discharged into the mine void at that time). The total ingress volume pumped from ERPM, excluding 'imported' service water, thus amounted to 20.93 Mℓ/d.

Only two years of pumping records from DRD were available in 1995. The pumped water represented water from DRD itself (which was still in production) and leakage from neighbouring Rand Leases. Scott (1995) reported that 18.06 Mℓ/d was pumped from DRD, inferred as comprising 10.23 Mℓ/d ingress into DRD, 4.74 Mℓ/d ingress into Rand Leases and 3.09 Mℓ/d service water.

The total ingress into the Central Rand prior to 1995, representing the sum of non-service water pumped from ERPM and DRD, therefore amounted to about 35.9 Mℓ/d.

Boer *et al*. (2004) carried out an assessment of sources of ingress into the defunct mines of the Central and Eastern basins which included, inter alia, pumping records extracted from company annual reports. The pumping records for the Central Basin mines are shown in **Table 7.1.** In the period 1978 to 1989 when only DRD and ERPM were still operating and records were relatively complete, pumped volumes ranged from 44.9 Mℓ/d to 71.5 Mℓ/d, averaging 59.1 Mℓ/d. It is not clear whether service water was excluded, but it appears that this was not taken into account, and the average is therefore considered to include service water. According to Scott (1995), total service water for DRD and ERPM amounted to 13.7 Mℓ/d, and hence the net natural ingress volume based on the Boer *et al*. (2004) analysis reduces to an average of 45.5 Mℓ/d in the period 1978 to 1989. The data in the period after the closure of DRD in 1999 (**Section 7.3.1**) indicate a rise in pumped volume to about 50 Mℓ/d. The reason for this sudden increase is not clear.

Scott (1995) investigated the relationship between rainfall and pumping volumes and plug pressures at ERPM and found an extremely weak correlation indicating a 4- to 7-day response time between plug pressure and rainfall. Scott (1995) suggested that this reflected direct ingress from streams crossing the disturbed zone. Pumping volumes appeared not to correlate with rainfall, which was attributed to the pumping regimen adopted by the mine, e.g. pumping during the night and weekends to reduce costs.

Krige (2001), based on flow measurements in the Klip River and its tributaries, arrived at an estimated ingress of 32.51 Mℓ/d. Total ingress into the Central Basin as indicated by Scott (1995) amounted to between 27.5 Mℓ/d and 35.0 Mℓ/d. Winde *et al*. (2011), largely following Scott (1995), calculated the total ingress at 33.92 Mℓ/d. The estimated total dry season ingress of 76 Mℓ/d and wet season ingress of 99 Mℓ/d reported by Van Biljon and Walker (2001) are higher than the average pumping rate of ca. 60 Mℓ/d, and therefore regarded as unrealistic.

As is evident from the latest data available, the mine water level of the Central Basin equalised in May 2010 when the water in the eastern parts of the basin reached the perched level in the DRD area (**Figure 7.14**). Utilising this fact, it is possible (following the approach described in **Section 6.5.3**) to calculate the ingress rate in the Central Basin from the Rison Consulting void curves (**Figure 7.15** and **Figure 7.16**) (TCTA, 2011), combined with the water level rise statistics of the Central Basin as measured at Crown Mines No. 14 Shaft. The “conservative” curve (**Figure 7.16**) is based on the data presented by Rison Consulting, whereas the “progressive” line allows for possible over-estimation in the void volume reduction between 1 000 and 1 400 m amsl. The latter represents a worst case scenario.

The results of the calculations are presented in **Figure 7.17** and **Figure 7.18**. The observed data was used to develop the conservative model (**Figure 7.17**), and the linear equation (**Figure 7.16**) for the progressive model (**Figure 7.18**).

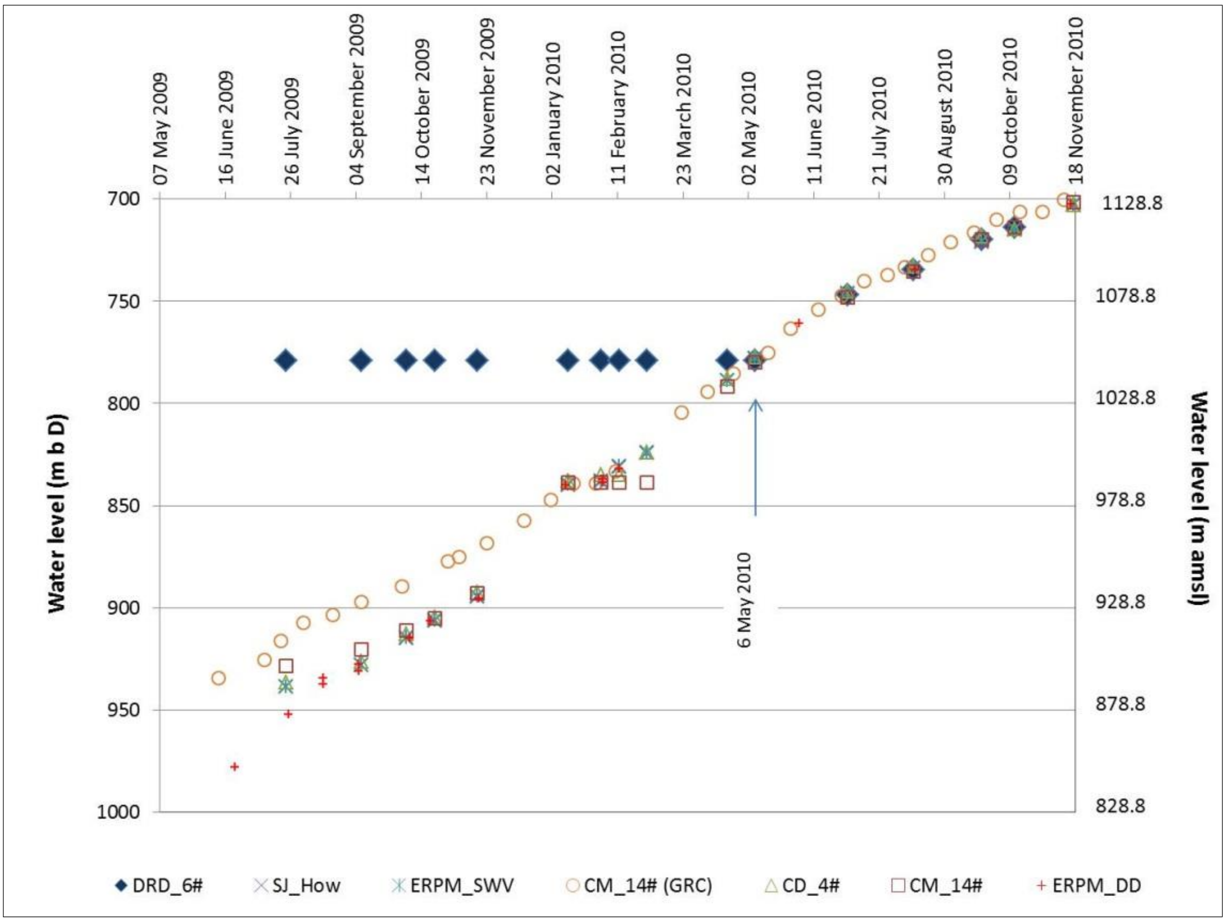
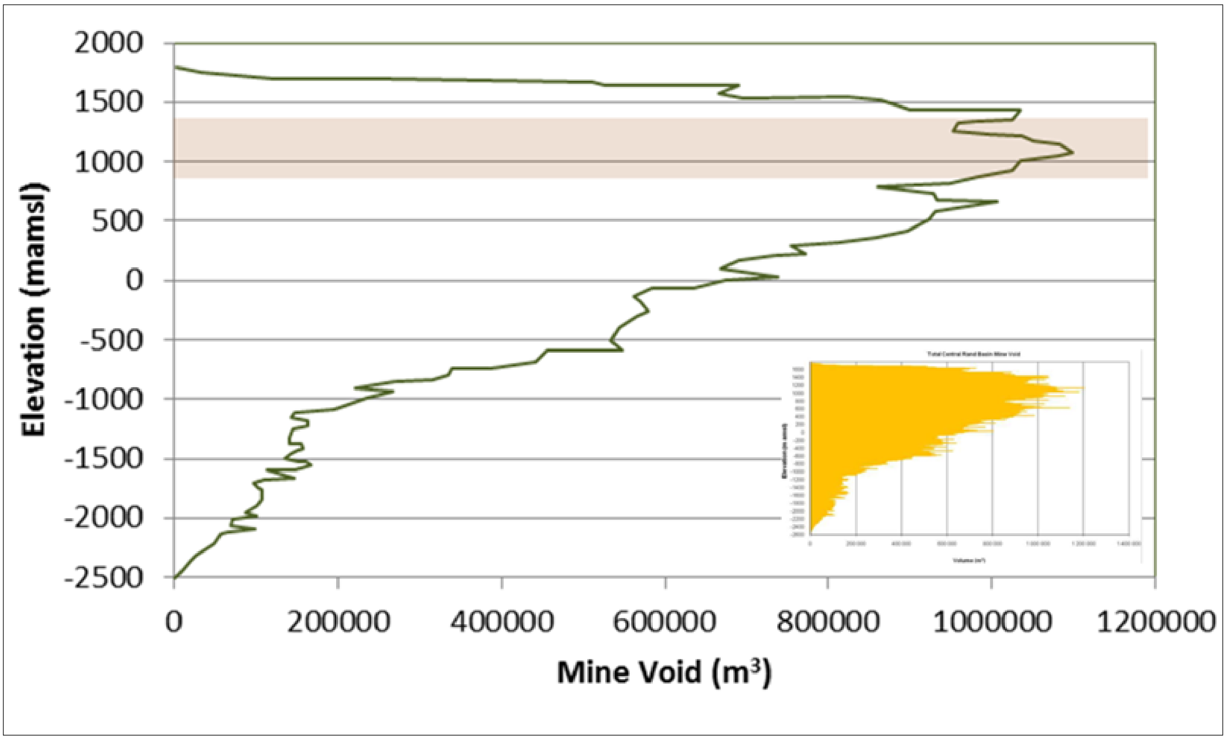
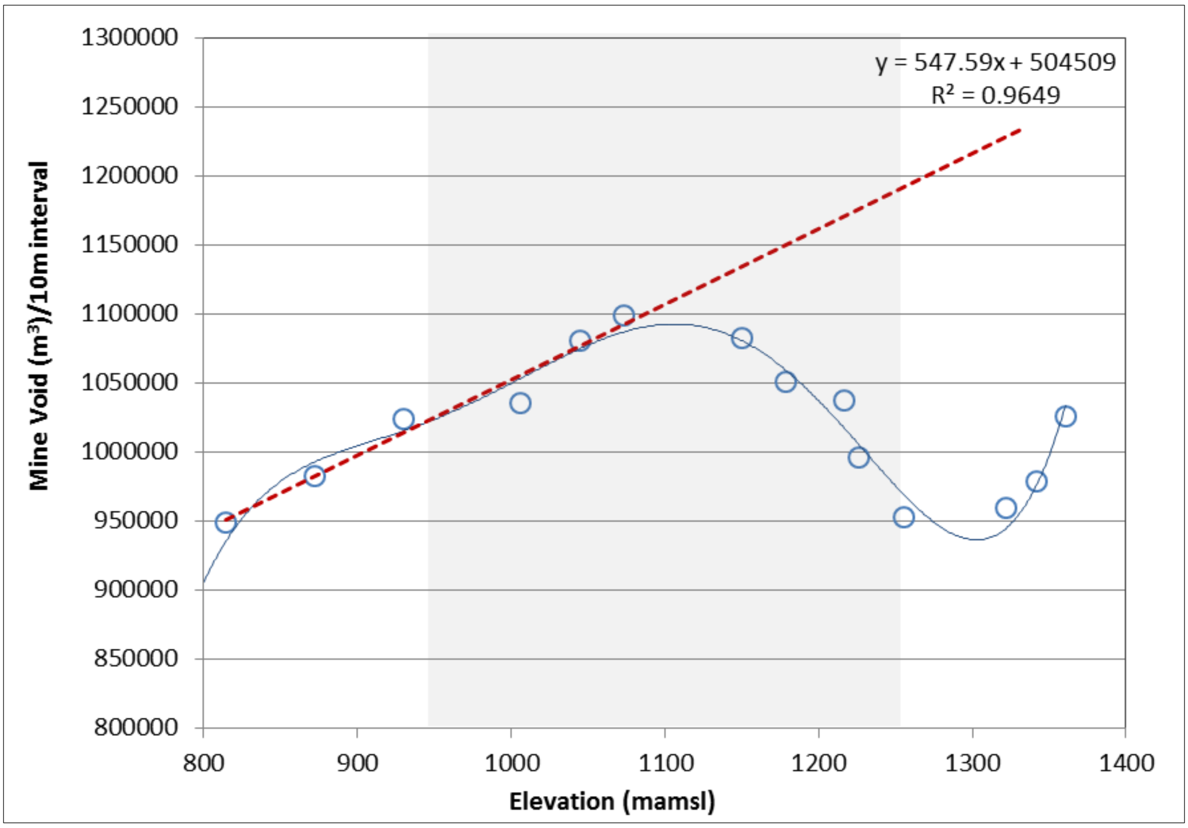


Figure 7.14: Detail of merging of the DRD compartment with the CM and ERPM compartments



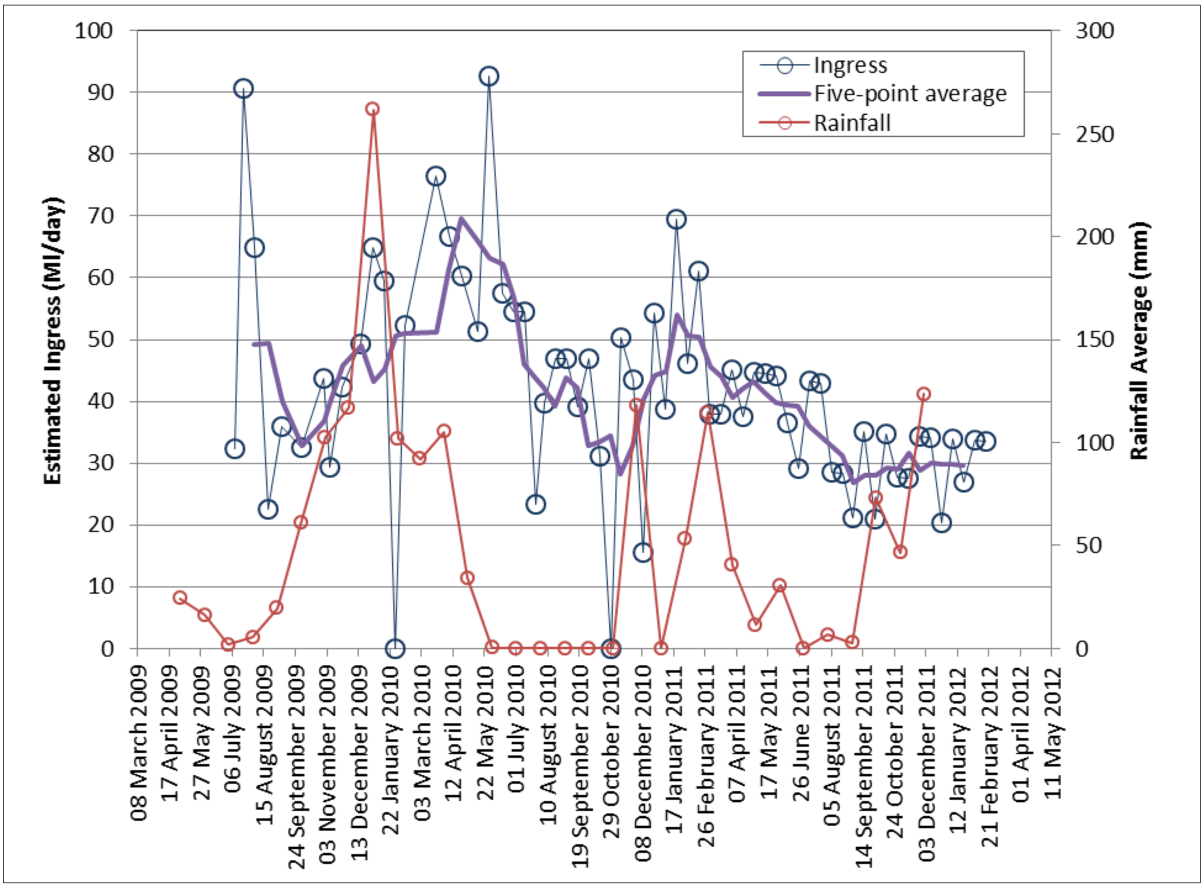
Note: Shaded area covers the water levels since merging of the sub-basins. Inset is the void curve of Rison Consulting

Figure 7.15: Digitised void curve for the Central Basin



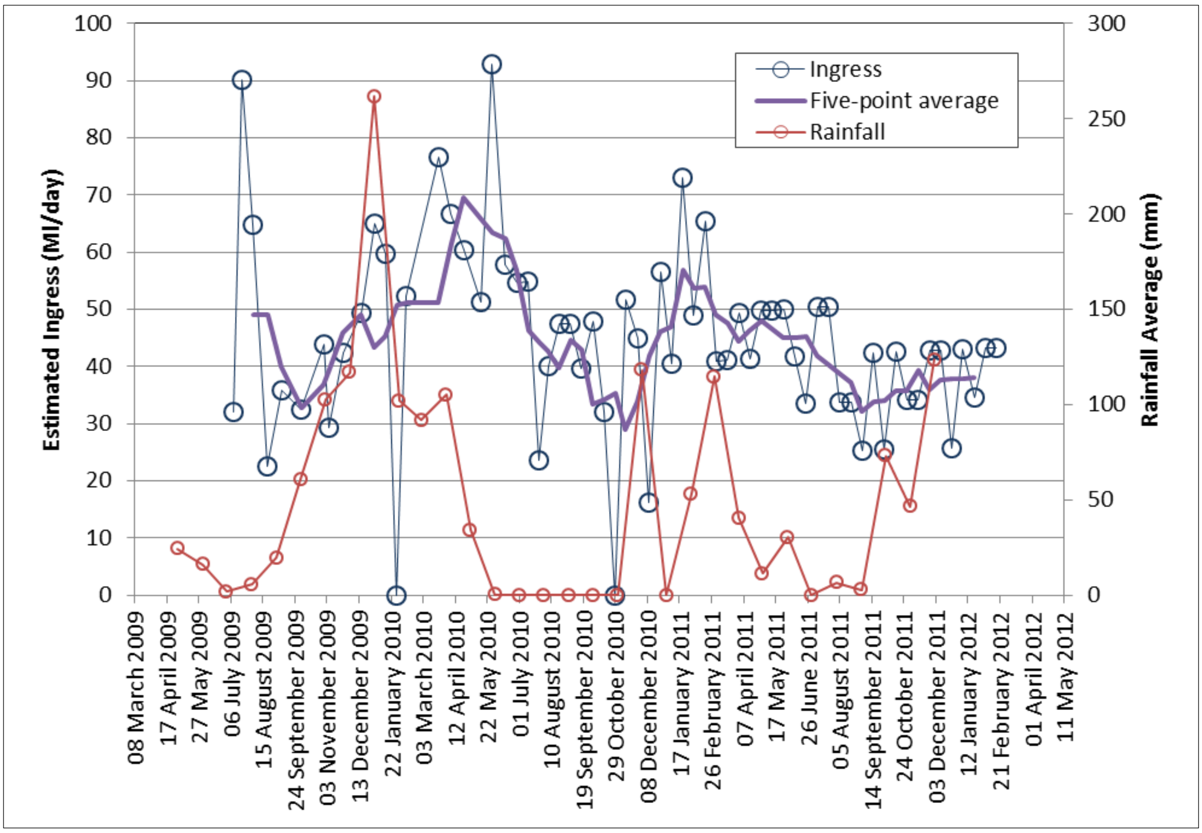
Note: Trend lines: Curved line (conservative) and red dotted lines (progressive).

Figure 7.16: Detail of the digitised void volume over the elevation interval (shaded grey)



Note: Derived from the rate of water level rise and the curved line of conservative best fit (Figure 7.16) of the void volume

Figure 7.17: Estimated total ingress with time in the Central Basin



Note: Derived from the rate of water level rise and the straight line of progressive best fit (Figure 7.16) of the void volume

Figure 7.18: Estimated total ingress with time in the Central Basin

Keeping in mind that the void volume curve might not be accurate to the detail illustrated here, scrutiny of **Figure 7.17** and **Figure 7.18** suggests that:

- The short time range of the data does not allow any firm inferences to be made on the relation between the seasonal trends and the regional rainfall pattern (average of the three stations Springs, OR Tambo and Emmarentia Botanical Gardens). Periods of increasing ingress (e.g. September 2009 to April 2010) correspond to periods of higher rainfall. However, the excessive, and sustained, rainfall event over the summer of 2009 was not repeated in later years (**Figure 7.18**), leading to progressively lower ingress rates;
- The seasonal variation may reflect mainly the relatively slow ingress of "imported water" due to human activities during summer (Krige, 2001), rather than rapid inflow during rainstorms, hence the slow and somewhat inconsistent response of ingress to rainfall;
- Ingress maxima appear to be gradually decreasing with time. This may in part be due to progressively smaller summer rainfall spikes over the time period considered, or to the expected lowering of the hydraulic head of water flowing into the void via fractured aquifers, or both;
- The ingress minima decrease at an average rate of approximately 5 Mℓ/100 m rise in water level. This decrease is interpreted to give an indication of the maximum decrease in the rate of flow of fracture/fissure water into the mine void; and
- The current ingress average of 30 or 38 Mℓ/d (depending on void model and the accuracy of the associated void volume data) is in agreement with the estimates of Scott (1995),

Krige (2001) and Winde *et al*. (2011), and within the wide range of 34 to 84 Mℓ/d reported in the WUC (2009) study.

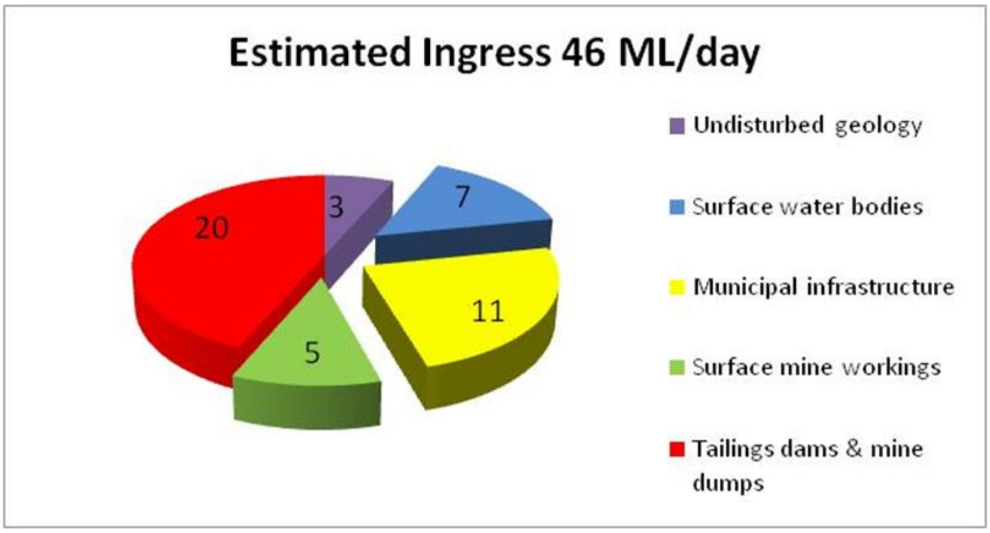
7.5.4 Minimising surface water ingress

It is considered that the ingress in the Central Basin appears to be more susceptible to wet and dry seasons due to direct ingress of infiltration through the extensive shallow mine excavations along strike and the numerous surface water bodies. A rate of 46 Mℓ/d has been used as the nominal ingress rate to allow for higher inflows during the wetter periods (**Section 7.6.1**). In order to minimise surface water ingress if possible, an initial prioritisation of the main categories of sources as defined in **Table 6.4** has also been made for the Central Basin (**Table 7.8**). **Table 7.8** indicates that the majority of ingress is via tailings and dumps (44%). Municipal leaks might account for 24% of the water entering the void, and surface water bodies crossing more permeable zones for 14%.

Table 7.8: Prioritisation of ingress control measures

Source	Percentage of Total Ingress Volume	Expected Ingress Volume (Mℓ/d)	Priority of Improved Ingress Control[2]
Undisturbed geology[1] /Shallow aquifers	7	3	5
Surface water (dams, rivers, wetlands) (WUC, 2009)	14	7	1
Municipal infrastructure (leaking mains and sewerage, stormwater runoff)	24	11	2
Surface mine workings (open pits, shafts, inclines) (WUC, 2009)	11	5	3
Tailings dams and mine dumps (Winde *et al*., 2011)	44	20	4
Total	100	46	

1: The remaining water not included in WUC and Winde is an estimate on the basis that the Central Basin is highly urbanised so there is more runoff to stormwater and sewer and less recharge through the undisturbed geology. Recharge through the undisturbed geology has been estimated as 5% of the MAP over the 15kmx6km area of the Central Basin.
2: A priority "5" has been given to the "undisturbed geology" as no practical and feasible improvements to ingress control can be used for this source



Exploded bars indicate sources that can be controlled and inset bars are sources that cannot be controlled.

Figure 7.19: The expected ingress volume for the Central Basin

The water bodies that cross major faults, dykes and shallow undermined areas, should be canalised across these potentially more permeable structures. Krige (2001) and others (WUC, 2009) have identified a number of areas of water ingress in the Central Basin, particularly where surface streams cross areas of shallow undermining. Canalisation of these streams, and possibly also grouting of permeable strata, will reduce water ingress into zones of shallow undermining. Krige (2001) estimates that ingress could be reduced by as much as 32.5 Mℓ/d. The construction of a canal to the south of Florida Lake has been commissioned, and additional sites for canal construction have been identified.

The loss/leakage of water from the municipal water supply networks (attributable to decaying infrastructure), as well as tree root growth into municipal systems, sewerage and storm-water reticulation systems, are suspected to contribute to ingress into the Central Basin. These possible sources will need to be investigated in collaboration with the Johannesburg and Ekurhuleni metropolitan councils.

As the tailings dams are re-worked, the source of water will be reduced, and ingress into the voids will decrease. Implementing ingress control and management measures with priorities 1 to 3 (**Table 7.8**) could theoretically reduce the ingress by 20 Mℓ/d. If only half of this is achievable, ingress could still be reduced by 10 Mℓ/d. Removal of the mine dumps as is currently underway, could reduce ingress further.

7.6 Pumping Volumes and Abstraction Points

7.6.1 Pumping volumes required

The main objective of the pumping exercise is to keep the water in the mining void below a pre-determined level. Since the ingress is variable (**Section 7.5.3**; **Figure 7.17**), having reached levels of 70 Mℓ/d in the wet season of 2009-2010, adequate freeboard and spare pumping capacity must be provided to prevent excessive water level fluctuations in the mine void during such periods. Scrutiny of **Figure 7.17** suggests that ingress stabilises at ca. 30 to 35 Mℓ/d, during the dry season (an indication of the likely base flow volumes), and suggesting that the abstraction rate will need to be greater.

During pumping, the water level fluctuation will be a function of the ingress, the pumping rate and mine void volume at a given elevation:

Water level rise/day = [Ingress (m^3/d) – Abstraction (m^3/d)]/Void Surface Area at ECL (m^3/m).

The estimated ingress rate over a three year period (**Figure 7.17**), and the void volumes determined by Rison (2001) allow the required pumping volumes to be modelled. The results are illustrated in **Figure 7.20**. For this model a constant void surface area of 1.1×10^5 m^2 at the preferred ECL of 1 467 m amsl has been assumed.

At an abstraction rate of 35 Mℓ/d the water level in the mine void is expected to rise at an average rate of about 0.1 m/d. At 45.5 Mℓ/d, a state of equilibrium is maintained, with water levels fluctuating in the interval ECL ± 25 m. At this rate, however, the water level in the void will rise during excessively wet seasons, and with insufficient freeboard may inundate the Gold Reef City Tourist Facility. Pumping at 50 Mℓ/d would lower the water level in average conditions to ca. 40 m below the preferred level over 965 days with increased costs. Allowing for maintenance and other contingencies, a minimum pumping capacity of 50 Mℓ/d is recommended.

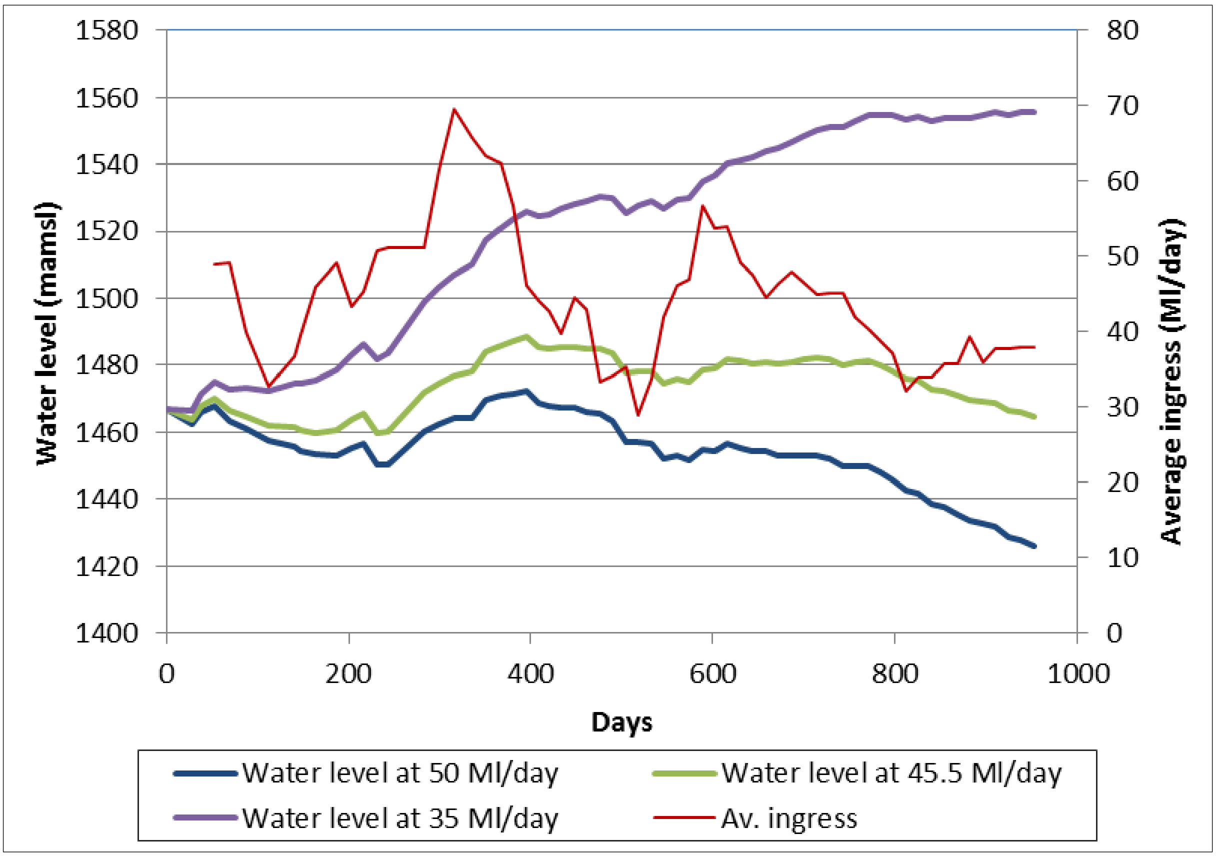


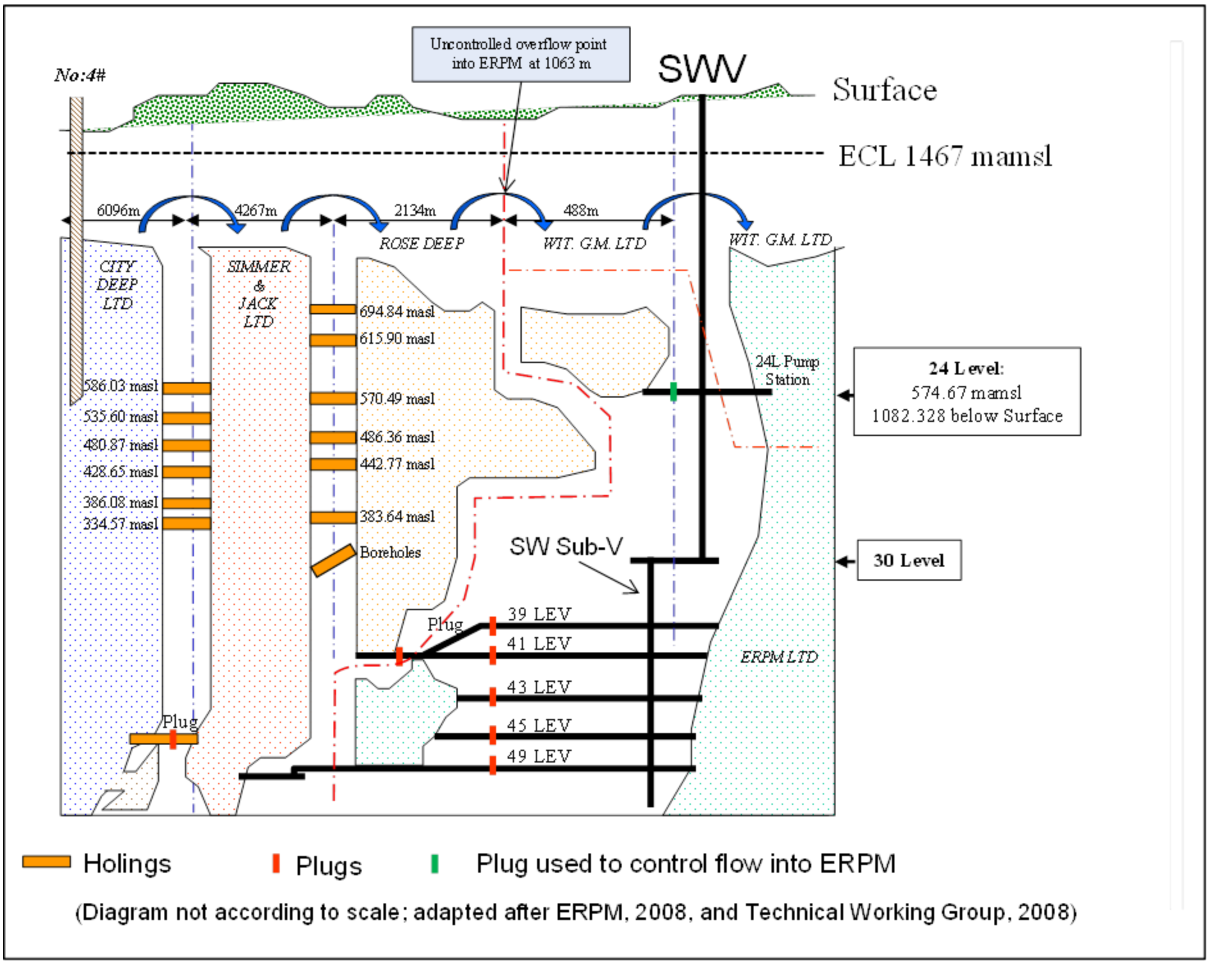
Figure 7.20: Pumping models for the Central Basin

In applying these results, the following sources of variance need to be considered:

- Rainfall patterns may vary from one period to the next; the 965 day period considered here includes a particularly wet season (2010) and what appear to be more normal rainfall seasons (2011 and 2012);
- The "progressive" model (**Section 7.5.3**, **Figure 7.18**) selected for the calculation produces water levels that are on average 20 m deeper (after the 965-day run) than the "conservative" model;
- The proposed pumping volumes are based on the void volume estimates of Rison Consulting, and the pumping volume accuracy is therefore directly related to that of the void volume estimates; and
- A possible gradual decrease in direct ingress into the mine void of fractured aquifers due to increasing hydraulic equilibrium has not been considered. Crude estimates based on the calculated ingress minima (winter months) suggests a decrease of ca. 5 Mℓ/d over a 100 m elevation change. Since the current water level in the Central Basin is about 150 m below the ECL of 1 467 m amsl, the proposed pumping rates may be reduced by 5 to 8 Mℓ/d. However, monitoring is required before such reductions can be applied.

7.6.2 Suitability of shafts for pumping

South West Vertical (SWV) Shaft at ERPM was identified in the TCTA (2011) study as the site where the pumps will be installed, largely because much of the necessary infrastructure was in place. However, much of this infrastructure has since been removed. A possible disadvantage of this shaft is its very deep connection with the mine void (24 Level, 1 080 m below surface) and the haulage at this level will have to carry most of the discharge. The shaft is connected at 30 Level to another shaft (South West Sub-vertical Shaft) which is well connected to the void at depth. If there is a collapse in the tunnel on 24 Level, water will be drawn into the shaft from considerable depth via the sub-vertical shaft (**Figure 7.21**). However, flow might be restricted because according to Mr Vivian Labuschagne (mine surveyor, DRD) the lower portion of SWV shaft was damaged in the 1990's and was not repaired. This may have affected the connectivity between the two shafts. Mr Labuschagne also mentioned that partial collapse had occurred in a dyke on 24 level.



Note: This Figure uses original mine return levels

Figure 7.21: Schematic diagram showing SWV and SW Sub-vertical shafts and their connections to the void

There is a ventilation shaft 500 m north-west of SWV shaft which could serve as back-up pumping location in the event of problems with SWV and could be connected directly to the HDS plant relatively easily (**Figure 7.22**). This shaft was considered in the STI investigation but was rejected because it is too small (it has a diameter of 6 m) and only connected to the void by a single tunnel. It is essential that the integrity of this shaft be safe-guarded in the future as possible backup abstraction point.

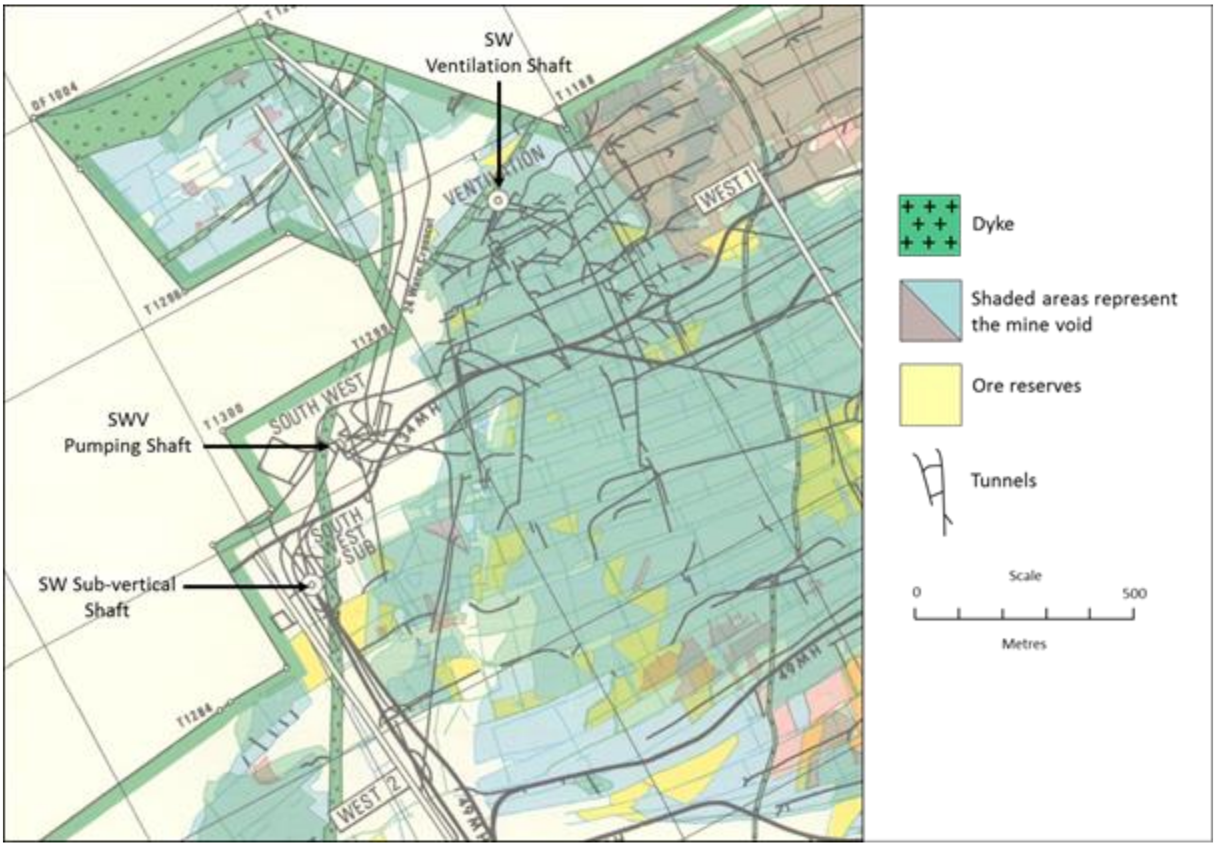


Figure 7.22: Extract from the Shareholder's Plan showing the SWV Shaft area

The potential flow paths of ingress water in the Central Basin have been conceptually investigated. The void is divided into three sub-compartments as described in Section 7.3.2. After cessation of pumping at ERPM in 2008, it was observed that the water level in the CMR-SJ remained static until the water level in the ERPM compartment reached 820 m amsl, after which the CMR-SJ water level began to rise in concert with ERPM (**Figure 7.5**). This suggests that water was decanting from the CMR-SJ compartment into the ERPM compartment at that level. The water level in the DRD-RL compartment appears to have remained static until the ERPM compartment had reached a level of 1 049 m amsl, when all of the sub-compartments began to rise together, implying decanting from the DRD-RL sub-compartment at this level.

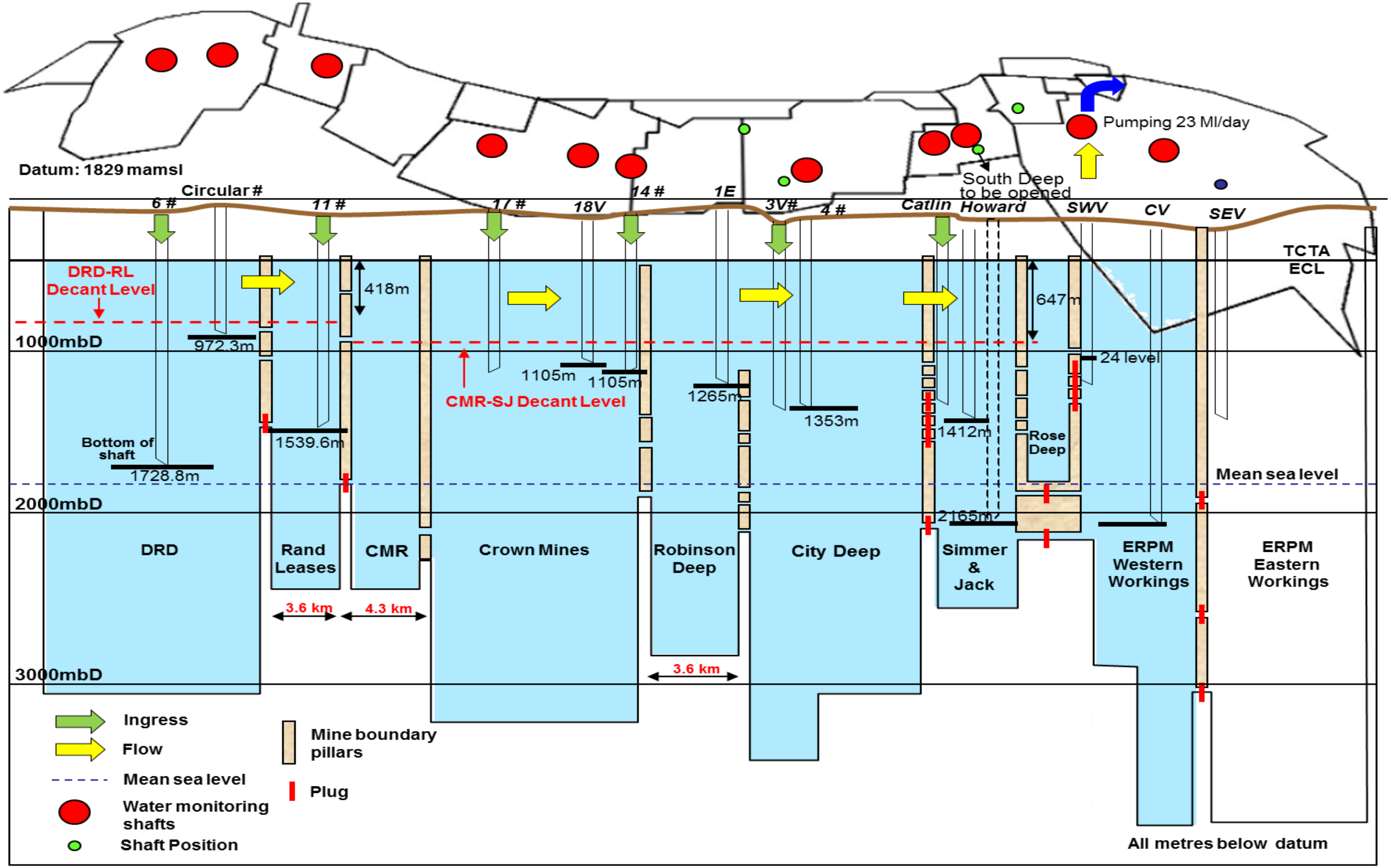


Figure 7.23: Conceptual diagram showing the water flow through the mine void of the Central Basin, with pumping at SWV Shaft

These decant levels have implications for the lateral flow of ingress water. The decant point for the DRD-RL sub-compartment is located at a depth of 418 m below the TCTA ECL (1 467 m amsl) and the decant point for the CMR-SJ sub-compartment lies at 647 m below the ECL. Flow of water from the west to the east will thus only involve the upper 600 m or so of the water column (**Figure 7.23**) which will promote stratification of the water in the deeper void. Deep, potentially severely polluted water in the DRD – RL and CMR – SJ sub-compartments is unlikely to contribute to the water pumped from ERPM at SWV Shaft.

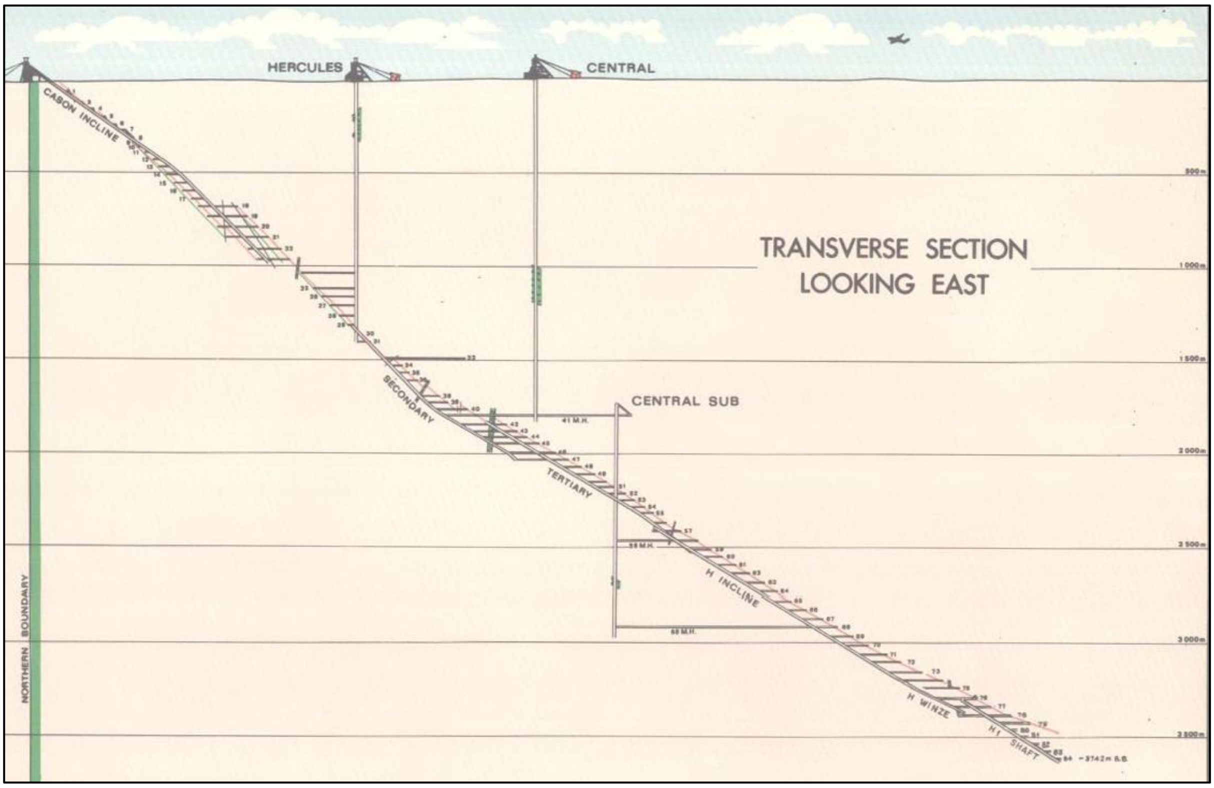
In a long-term solution, other pumping strategies should be investigated which could involve multiple extraction points which have greater connectivity with the void at a shallow level.

A preferable long-term approach would be to abstract at SWV and up to four other locations. Like SWV Shaft, most of the vertical shafts still accessible today on the Central Rand intersect the void at great depth. The reason is that most of the shallower reefs were accessed by incline shafts. A detailed investigation of potential vertical shafts that may have greater interconnectivity would require a detailed study of multiple criteria and is beyond the scope of this study.

An incline shaft, compared to a vertical shaft, has the advantage that it is connected directly to the mine void at shallower depths, on multiple levels, and even without headgear can be easily accessed. The chances of stope or haulage collapse at shallow depths (less than 500 m) are also greatly reduced. However, preparing and equipping an incline shaft would require considerable lead times and the use of pumps capable of operating at an inclined orientation. There is also some risk regarding shaft stability, when considering incline shafts over vertical shafts, which would have to be evaluated on a case by case basis in the options analysis. Another important consideration is that the pump scenario should be able to manage pumping from different water levels. Submersible pumps would be recommended.

One such incline shaft which may be suitable for pumping is Cason Shaft, but is currently being worked by ERPM. This shaft is approximately 1 000 m deep, intersecting the mine void on multiple levels up to 1 599 m amsl (**Figure 7.24** and **Table 7.9**). Both Hercules and Central Shafts may have been filled.

Given the preference for multiple abstraction points, the problematic connectivity of shafts and the risks and uncertainties of equipping and pumping from shafts and inclines, an alternative strategy is to drill a number of new boreholes into carefully selected locations in the mine void, with good connectivity at shallow and other depths. This is considered further in DWA AMD FS 2012, Study Report No. 5: **"Technical Prefeasibility Report"**.



Note: Primary incline is well connected and extends approximately 1000 m below surface

Figure 7.24: North South cross-section of Cason Shaft

Table 7.9: Summary of level elevations in Cason Shaft

Cason Shaft (collar @ 1 643 m amsl)	Elevation (m below datum)	Elevation (m amsl)
1 level	230	1 599
2 level	256	1 573
3 level	289	1 540
4 level	317	1 512
5 level	361	1 468
6 level	405	1 424
7 level	432	1 396
8 level	460	1 369
9 level	488	1 340
10 level	514	1 315
11 level	548	1 281
12 level	584	1 245

7.6.3 Alternative options to pumping

Passive solutions allowing natural surface decant at preferred ECLs, rather than pumping were identified. A tunnel designed to intersect the Central Vertical (CV) Shaft at ERPM has previously been proposed, allowing Central Basin water to decant naturally into the Elsburgspruit (Boer *et al*., 2004). It was established that a 2 km long tunnel from 110 m below collar at CV Shaft to a point along the Elsburgspruit (1 570 m amsl) would offer the most practical and cost effective solution. Unfortunately this shaft has subsequently been filled. The length of the tunnel would now likely be far longer than previously conceptualised due to the practice of shaft filling in the ERPM area. An in-situ pumping or siphon solution may also be required to lower the water level to the required ECL. However, there is sufficient elevation difference between the surface decant point and the Elsburg wetland to allow for the construction of a treatment plant.

7.7 Water Qualities

7.7.1 Data utilised

Water quality data were compiled and synthesised from three principal sources, described below and summarised in **Table 7.10**:

a) Shaft sampling:

Two types of sampling technique have been developed for vertical shafts:

- Samples collected underground at the water surface in the shaft barrel accompanying water level monitoring; and
- Samples collected at various depths in the shaft water column using a depth point sampler aimed at determining potential stratification in the water column.

b) Underground sampling:

Underground samples were collected between 2005 and 2006 from two sites accessed from SWV Shaft on ERPM, Witwatersrand Gold Mine (Wits GM) overflow and Rose Deep plug. These sites represent stope water collected from approximately 1 080 m below surface.

c) Surface sampling:

A number of surface samples were taken from ERPM during 2005 to assess the quality of ingress water into the Hercules Compartment at ERPM. The surface sample sites range from streams to tailings dams and surface water bodies.

Table 7.10: Water quality sampling data utilised in the Central Basin

<table>
<tr><th>Mine</th><th>Location</th><th>Sample Type</th><th>Source</th><th>n</th></tr>
<tr><td>DRD</td><td>06#, Circular</td><td>Shaft sampling, Depth profile</td><td>CGS</td><td>41</td></tr>
<tr><td rowspan="2">Crowns Mine</td><td>14#, 14# incl.</td><td>Shaft sampling</td><td>CGS</td><td>7</td></tr>
<tr><td>17#</td><td>Shaft sampling, Depth profile</td><td>CGS</td><td>13</td></tr>
<tr><td>City Deep</td><td>03Vent#, 04#</td><td>Shaft sampling</td><td>CGS</td><td>37</td></tr>
<tr><td>Simmer and Jack</td><td>Catlin#, Howard#</td><td>Shaft sampling</td><td>CGS</td><td>9</td></tr>
<tr><td>ERPM/Wits GM</td><td>Various</td><td>Surface Monitoring Point</td><td>CGS</td><td>25</td></tr>
<tr><td rowspan="2">ERPM</td><td>Central Vertical#</td><td>Shaft sampling</td><td>CGS</td><td>1</td></tr>
<tr><td>Wits GM overflow and Rose Deep plug</td><td>Underground</td><td>CGS</td><td>14</td></tr>
<tr><td colspan="4">Total no of samples</td><td>147</td></tr>
<tr><td colspan="5"># = Shaft, n = Number of samples</td></tr>
</table>

7.7.2 Water chemistry

The water quality of the Central Basin at different sample localities is summarised in **Table 7.11**. Except for the DRD 6 Shaft and ERPM CV Shaft, the water in the Central Basin is generally acidic with high levels of dissolved solids. **Table 7.12** presents the summary composition ranges (as percentiles) of the composite water quality dataset.

It is considered likely that the extensive shaft sampling data (**Table 7.11**) reflect dilution from surface ingress and possibly some degree of reaction with shaft cement linings. **Table 7.13** presents percentile values for the underground mine water samples only. Should pumping take place from deeper areas, such as proposed for the STI at SWV Shaft (TCTA, 2011), these are more likely to be broadly representative of the expected water qualities.

7.7.3 Change of water quality with time

No meaningful data on this aspect for the Central Basin could be sourced. However, the general considerations (discussed in more detail in **Section 10.3**) apply equally well for the Central Basin. It can be expected that the AMD that formed initially, will be in homogeneously distributed and layered due to localised dilution by uncontaminated water. Near the upper reaches of the void, surface water can be expected to form deep columns in the shaft voids. The DRD No. 6 Shaft is a good example, where the relatively good quality water recorded (**Table 7.11**) most likely comes from the surface via human activity. However, the effects of possible deep void water convection are unknown.

Another factor that needs to be considered is that before 1930, mine workings were filled to a depth of several hundred metres with sand and rubble, but mainly with ash derived from the many steam engines used in stamp mills, hoists and locomotives (Scott, 1995). This practice physically reduced the mine void but can also be expected to have an influence on the water chemistry. The alkaline nature of coal ash that can lead to pH values of between 10 and 12 would tend to neutralise the early-formed AMD. However, the degree of interaction of the ash with void water over time is unknown.

Table 7.11: Water quality (95th percentiles) of selected sites in the Central Basin

Elements	Units	Shaft				Underground				Surface			
		DRD 6	DRD Circular	CM 14	CM 17	CD 03Vent	CD 4	SJ Catlin	SJ Howard	ERPM CV	Wits GM Overflow	Rose Deep	ERPM Surface
n		23	18	7	13	14	23	8	1	1	6	6	23
pH*		7.2	3.0	3.4	3.9	4.3	4.4	3.3	5.0	7.4	2.4	2.6	3.4
EC	mS/m	94	189	264	350	196	309	377	327	301	412	473	575
TDS^	ppm	980	1 828	2 525	3 867	1 085	2 215	4 507	2 695	2 263	4 251	4 478	4 364
Temp	^{o}C	25.4	25.3	27.0	30.8	27.5	27.6	28.4	19.8	21.0	24.5	27.2	32
Tot Alk	mg/ℓ $CaCO_3$	129	16	25	49	29	40	41	89	44	3	37	271
P Alk	mg/ℓ CaCO3	46	91	50	62	34	46	35	52	16	97	95	70
Na	mg/ℓ	56	69	153	195	72	172	209	106	243	172	169	225
Mg	mg/ℓ	46	78	93	170	66	102	232	160	153	261	208	205
Al	mg/ℓ	2	51	1	11	10	2	1	10	20	195	106	36
K	mg/ℓ	4	4	11	13	6	9	18	10	36	5	13	49
Ca	mg/ℓ	113	209	323	490	132	317	626	354	551	281	629	650
Fe	mg/ℓ	1	14	71	214	2	3	173	75	5	48	114	127
Mn	mg/ℓ	0	4	13	22	5	18	23	48	7	50	46	11
F	mg/ℓ	1	36	4	6	2	2	0	2	nd	4	4	5
Cl	mg/ℓ	37	35	57	68	57	61	75	166	108	147	136	259
NO_3	mg/ℓ	42	19	26	39	53	19	37	31	9	34	28	37
SO_4	mg/ℓ	675	1 328	1 769	2 631	671	1 504	3 107	1 724	1 124	3 029	3 005	2 750
Li	µg/ℓ	48	120	137	199	126	167	290	198	24	448	504	262
Be	µg/ℓ	1	16	1	2	4	2	1	9	1	26	19	4
B	µg/ℓ	850	591	714	559	1 109	689	451	1 225	50	350	938	3 529
V	µg/ℓ	3	3	1	2	2	3	6	1	19	14	5	9

Elements	Units	Shaft				Underground				Surface			
		DRD 6	DRD Circular	CM 14	CM 17	CD 03Vent	CD 4	SJ Catlin	SJ Howard	ERPM CV	Wits GM Overflow	Rose Deep	ERPM Surface
Cr	µg/ℓ	131	154	77	56	85	132	173	76	175	160	96	131
Co	µg/ℓ	18	1 956	136	522	749	722	341	2 634	536	5 814	4 397	1 164
Ni	µg/ℓ	132	7 017	326	1 671	1 623	915	772	2 440	737	12 935	9 853	2 027
Cu	µg/ℓ	64	744	86	232	151	242	82	802	48	377	310	324
Ga	µg/ℓ	40	50	27	66	45	47	56	43	8	72	71	6
As	µg/ℓ	42	31	31	42	34	32	22	116	25	33	155	1
Se	µg/ℓ	11	12	8	11	12	14	10	22	13	46	45	12
Rb	µg/ℓ	6	8	28	33	17	26	42	34	26	19	45	50
Zn	µg/ℓ	2	4	3	4	4	3	6	7	4	12	10	3
Sr	µg/ℓ	581	433	309	794	532	562	510	776	1 054	698	639	510
Mo	µg/ℓ	8	3	3	3	3	3	3	3	5	3	3	6
Ag	µg/ℓ	5	6	2	8	2	2	1	1	5	15	15	1
Cd	µg/ℓ	1	8	1	4	11	5	3	8	6	16	12	3
Te	µg/ℓ	1	1	1	1	1	1	1	1	1	1	1	1
Ba	µg/ℓ	798	1 078	701	1 396	903	909	1 601	855	2 870	1 753	1 819	105
Tl	µg/ℓ	1	1	1	1	1	1	1	1	5	1	1	1
Pb	µg/ℓ	156	547	461	205	324	282	1 109	153	418	131	354	399
Bi	µg/ℓ	1	1	1	1	1	1	1	1	3	4	1	1
U	µg/ℓ	7	231	13	64	69	19	13	57	30	703	569	567
*5th Percentile ^ Estimated by summation of reported 1salts Numbers rounded													

Table 7.12: Water quality range (percentiles) of the combined data for the Central Basin

Parameter	Unit	n	Percentile				
			95^{th}	90^{th}	50^{th}	10^{th}	5^{th}
T	^{o}C	119	28.4	27.3	23.1	20.4	19.3
pH*		119	3.2	3.3	5.0	7.7	8.1
EC	mS/m	119	354	333	187	84	82
TDS	mg/ℓ		3 695^	3 056^	1 624^	557	544
Tot Alk	mg/ℓ $CaCO_3$	110	125	120	25	3	3
P Alk	mg/ℓ $CaCO_3$	110	85	73	25	14	12
Bicarb Alk	mg/ℓ	110	88	79.2	0	0	0
Carb Alk	mg/ℓ	110	61	42	3	0	0
Hydrox Alk	mg/ℓ	110	150	101	15	0	0
Na	mg/ℓ	109	185	171	72	41	39
Mg	mg/ℓ	109	161	147	64	35	33
Al	mg/ℓ	109	44	40	0.8	0.05	0.05
K	mg/ℓ	109	14	11	5	1	1
Ca	mg/ℓ	109	483	402	180	89	86
Fe	mg/ℓ	109	177	162	1	0.05	0.05
Mn	mg/ℓ	109	20	18	5	0.03	0.02
F	mg/ℓ	109	3	3	0	0	0
Cl	mg/ℓ	109	69	64	46	19	18
NO_3	mg/ℓ	109	49	44	18	4	1
SO_4	mg/ℓ	109	2 464	2 037	1 083	289	266
Li	µg/ℓ	109	194	171	88	19	16
Be	µg/ℓ	109	12	11	1	1	1
B	µg/ℓ	109	916	540	165	25	25
V	µg/ℓ	109	4	3	1	1	1
Cr	µg/ℓ	109	147	123	39	5	5
Co	µg/ℓ	109	1 858	1 669	423	8	4
Ni	µg/ℓ	109	6 617	5 699	598	106	93
Cu	µg/ℓ	109	688	552	70	3	3
Zn	µg/ℓ	109	4 019	3 316	1 237	374	319
Ga	µg/ℓ	109	49	42	3	3	3
As	µg/ℓ	109	37	34	1	1	1
Se	µg/ℓ	109	13	11	3	3	3
Rb	µg/ℓ	109	36	31	16	3	3
Sr	µg/ℓ	109	638	574	485	320	256
Mo	µg/ℓ	109	6	5	3	3	3
Ag	µg/ℓ	109	4	2	1	1	1
Cd	µg/ℓ	109	6	5	1	1	1
Te	µg/ℓ	109	1	1	1	1	1
Ba	µg/ℓ	109	1 031	903	26	5	5
Tl	µg/ℓ	109	1	1	1	1	1
Pb	µg/ℓ	109	506	302	75	18	13
Bi	µg/ℓ	109	1	1	1	1	1
U	µg/ℓ	109	219	198	11	6	5
^Estimated Data rounded #pH values in reverse percentile order, e.g. 95^{th} percentile is 5^{th} percentile							

Table 7.13: Expected water quality range (percentiles) of the Central Basin

Parameter	Unit	Percentile						
		95th	90th	75th	60th	50th	10th	5th
T	°C	27	26	25.3	23.2	23	22	22
pH#		2.4	2.5	2.8	2.9	3.0	4.3	4.4
EC	mS/m	465	450	412	405	397	371	371
TDS^	mg/ℓ	5 118	4 952	4 429	4 319	4 363	4 085	4 078
Tot Alk	mg/ℓ $CaCO_3$	34	29	8.9	2.5	2.5	2.5	2.5
Na	mg/ℓ	171	170	169	134	122	110	108
Mg	mg/ℓ	258	249	201	177	172	159	118
Al	mg/ℓ	193	184	133	129	122	21	10
K	mg/ℓ	13	12	7	5	5	3	3
Ca	mg/ℓ	563	459	403	351	279	243	241
Fe	mg/ℓ	108	94	48	41	40	2	1
Mn	mg/ℓ	50	50	49	47	47	24	13
F	mg/ℓ	4	4	2	2	1	0	0
Cl	mg/ℓ	146	144	141	138	137	87	84
NO_3	mg/ℓ	34	33	29	26	23	12	10
PO_4	mg/ℓ	15	11	0	0	0	0	0
SO_4	mg/ℓ	3 062	3 041	2 953	2 879	2 831	2 597	2 429
Li	µg/ℓ	495	450	428		372	290	274
Be	µg/ℓ	25	24	23	21	20	4	2
B	µg/ℓ	712	361	318	300	280	245	214
V	µg/ℓ	12	9	4	1	1	1	1
Cr	µg/ℓ	148	130	129	100	87	5	5
Co	µg/ℓ	5 760	5 637	5 205	4 923	4 684	1 200	601
Ni	µg/ℓ	12 850	12 633	11 669	11 122	10 589	2 600	1 268
Cu	µg/ℓ	376	375	371	332	328	40	28
Zn	µg/ℓ	12	11	9 625	9 195	9	2	1
Ga	µg/ℓ	88	79	19	33	3	3	3
As	µg/ℓ	115	55	39	33	31	1	1
Se	µg/ℓ	47	46	45	42	40	10	6
Rb	µg/ℓ	42	38	25	19	19	15	15
Sr	µg/ℓ	697	693	661	638	634	493	443
Mo	µg/ℓ	3	3	3	3	3	3	3
Ag	µg/ℓ	15	15	15	1	1	1	1
Cd	µg/ℓ	15	12	12	11	11	1	1
Te	µg/ℓ	1	1	1	1	1	1	1
Ba	µg/ℓ	2 213	2 053	442	18	11	5	5
Tl	µg/ℓ	1	1	1	1	1	1	1
Pb	µg/ℓ	276	132	80	35	28	7	5
Bi	µg/ℓ	2	1	1	1	1	1	1
U	µg/ℓ	695	682	657	645	606	123	56
Number of samples = 12 ^Estimated Data rounded # pH values in reverse percentile order, e.g. 95th percentile is 5th percentile								

Considering the above, it would be prudent to expect that unless the abstraction rate matches the ingress, the water quality would at first deteriorate (as exemplified by the water quality over time in 17 Winze of the Western Basin; **Figure 6.19**). Prolonged pumping will tend to stabilise the chemistry, depending on the degree of mixing and the extent to which channelling is effected during the pumping exercise. It is not possible to predict how the water quality might fluctuate over relatively short time periods when pumping commences and the flow regime establishes itself.

7.8 Summary and Recommendations

7.8.1 Critical Water Levels

The ECL is determined to be at an elevation of 1 520 m amsl. This is based on an estimated depth of 100 metres below surface at ERPM, and should adequately protect the shallow aquifer.

The mining museum at 1 484 m amsl in Crown Mines 14 Shaft at Gold Reef City (GRC) was taken to be the critical factor in determining the SECL. The SECL is set at an elevation of 1 474 m amsl to accommodate the lowering of the double decker conveyance and to ensure that the museum can still be visited as a heritage site. If the SECL is used, then the TOL must ensure that there is sufficient freeboard to allow for potential slow flow rates between GRC and the abstraction site(s).

For a detailed comparison of the important water levels chosen in this and previous reports, please refer to **Table 7.15**.

7.8.2 Ingress

A summary of the ingress predictions by various studies is given in **Table 7.14**, with and without ingress control measures. For this study, it is assumed that a reduction in ingress of at least 10 Mℓ/d could be achieved by canalising surface water features crossing shallow workings, dykes and faults, by continuing to upgrade the ageing water reticulation and sewerage systems and by on-going re-working of the mine dumps. As a conservative estimate, half the estimated ingress from these sources has been applied. Additional reduction in the ingress volume could possibly be obtained by applying ingress control measures to the remaining sources. The practicality and cost implications can however only be established once a more detailed study is undertaken.

Table 7.14: Summary of predicted ingress volumes in the Central Basin

Information Source	Predicted Ingress Volume (Mℓ/d) with no ingress control		Predicted Ingress Volume (Mℓ/d) with improved ingress control (-10 Mℓ/d)	
	Average	Range	Average	Range
WUC (2009)	59	47 - 102	49	37 – 92
This Study	46	30 - 90	36	24 - 74
TCTA (planned pumping rate)	57	34 -84	47	24 - 74

- The planned pumping rates proposed by the TCTA report compare well with the predicted range of ingress volumes and would also cater for possible climate change (**Section 4.2**).
- Realistically, the ingress volume could be reduced by about 10 Mℓ/d if the ingress control measures as described above can be implemented.

7.8.3 Pumping rates

Calculations based on estimated void volumes and ingress rates (this study) indicate that a state of equilibrium could possibly be maintained at a pumping rate of 46 Mℓ/d, with water levels fluctuating within approximately 25 m of the ECL. Pumping at 50 Mℓ/d would tend to lower the water level below the preferred static water level, but is the recommended minimum pumping capacity to enable high flows to be managed without an excessive freeboard. This might be a preferred volume to abstract, allowing for freeboard, maintenance and other contingencies.

There are concerns regarding the STI pumping site at South West Vertical Shaft due to its very deep connection with the mine void and that one haulage will have to carry the entire void discharge. A collapse in the haulage could have serious consequences. In a long-term solution, other pumping strategies should be investigated which could involve multiple extraction points that have greater connectivity with the void at a shallow level. Incline shafts, such as Cason Shaft, or preferably boreholes intersecting incline shafts or other suitable areas of the void, should be considered as potential alternative pumping sites. These offer a greater connectivity to the mine void at shallower levels.

7.8.4 Water quality

The Central Basin data is scattered over a wide field, reflecting the diversity of samples within the database, ranging from extremely contaminated surface samples to water within the potable range. However, the water quality of the Central Basin is generally acidic with high levels of dissolved solids. Prolonged pumping will tend to stabilise the chemistry, depending on the degree of mixing and the extent to which channelling is effected during the pumping exercise. **Table 7.13** is considered to reflect the best approximation available of the likely water quality should pumping take place from moderate to deep levels in the mine void.

Table 7.15: Comparison of key levels locations in the Central Basin

Central Basin - Comparison of Surface Levels at key locations and recommended ECLs, SECLs and TOLs													
Source Document	**Decant Level (m amsl)**	**Decant Point**	**ECL and SECL (m amsl)**	**Proposed Target Operating Level (m amsl)[1]**	**Depth of Proposed TOL (m) below lowest decant point**	**Rationale for Proposed TOL**	**Level not to be exceeded (e.g. bottom of aquifer)**	**Surface level at location of feature to be protected (m amsl)**	**Depth from surface at location of feature to be protected to TOL (m)**	**Other Considerations**	**Abstraction Shaft**	**Abstraction Shaft Collar Level (m amsl)**	**Depth of proposed TOL at Abstraction Shaft (m)**
IMC report (Dec 2010)[3]	Not given	Decant will occur in low-lying areas in the vicinity of the ERPM Mine in Boksburg and possibly elsewhere across the Witwatersrand.	1 503	1 503	Not given	Protection of dolomitic aquifer south of Boksburg	Not mentioned	Not given	Not given	Possible mining by CRG (bottom p 24, p 65)	Not specified	Not specified	Not specified
	N/A	Page 25	Table 7.4, page 65	Not defined, assumed to be equal to ECL of 1 503 m amsl	N/A	Table 10.1	N/A	N/A	N/A	Gold Reef City Tourist Attraction (Table 10.1)	N/A	SVW collar level calculated as 1 653 m masl from ECL at SWV of 150 m	Page 65 gives depth to ECL at SWV as 150 m
TCTA Due Diligence Report (2011)[4]	1 617	Cinderella East	1 517	1 467	150	Protection of the weathered and fractured aquifers within the basin	1 567	Not given	Not given	Mining by CRG down to a level of 1 278 m amsl (400 m below surface at the CRG Portal)	South West Vertical Shaft	1 653.24	186.24
	Table 1, page 10	Table 1 gives C. East as the decant point. Note - On p. 47 collar level for C. West is given as 1 614 m amsl, which is 3 m lower than C. East.	Table 1 gives ECL 1467 and Annexure B states that this includes 50 m buffer. Thus ECL of 1 467 equates to TOL.	Annexure B states that ECL includes 50 m buffer. Thus TOL 50 m below ECL of 1 517	Decant level minus TOL	Table 1, page 10	Annexure B: "These aquifers generally only extend 80-100 m below the surface providing a 50 m buffer to ensure the protection of these groundwater resources.". Level of aquifer thus assumed to be 50 m above ECL.	N/A	N/A	Chapter 7.2.3 p. 57	Table 26, p. 53	Table 24, p. 49. Collar level subsequently resurveyed by DWA as 1 699 m amsl	SWV Collar Level minus TOL

Central Basin - Comparison of Surface Levels at key locations and recommended ECLs, SECLs and TOLs

Source Document	Decant Level (m amsl)	Decant Point	ECL and SECL (m amsl)	Proposed Target Operating Level (m amsl)[1]	Depth of Proposed TOL (m) below lowest decant point	Rationale for Proposed TOL	Level not to be exceeded (e.g. bottom of aquifer)	Surface level at location of feature to be protected (m amsl)	Depth from surface at location of feature to be protected to TOL (m)	Other Considerations	Abstraction Shaft	Abstraction Shaft Collar Level (m amsl)	Depth of proposed TOL at Abstraction Shaft (m)
Long-term Solution[5]	1 620	Cinderella West	ECL: 1 520	1 500[2]	120	Protection of the weathered/ fractured aquifers	1 517	Not given	Not given	None given	South West Vertical Shaft	1 646	146
	Mine Voids Report, 3rd draft chapter 7.4.1, page 83.		This report, Chapter 7	20 m below ECL	Decant level minus TOL for ECL	Annexure B of TCTA Due Diligence report		N/A	N/A	N/A	Note - SWV identified as reference shaft, but alternative pumping locations should also be secured. (This report, Chapter 11.)	Note - This is the new collar level surveyed by DWA. Need to add data source to this.	SWV Collar Level minus TOL for ECL
			SECL: 1 474	1 454	166	Gold Reef City Level 5 museum	1 484	1 699	170	Possible mining level at 1 246 m amsl			192
			This report, Chapter 7	20 m below SECL	Decant level minus TOL for SECL	This report, Chapter 7		This report, Chapter 7	CM14 Collar level - TOL for SECL	This report, Chapter 7			SWV Collar Level minus TOL for SECL

1: The "freeboard" (or buffer) proposed for the LTS, being the difference between the ECL/SECL and the TOL was estimated for the long-term for when conditions are stable. A larger freeboard would be appropriate for the short-term, until seasonal and spatial variations of the water level have been established.
2: Although a TOL of 1 500 m amsl is proposed for the long-term, it is suggested that the TOL initially be kept at 1 470 m amsl to account for the spatial and temporal variations of the water level in the mine void.
3: Expert Team of the Inter-Ministerial Committee (2010) Mine water management in the Witwatersrand gold fields with special emphasis on Acid Mine Drainage. Report to the Inter-Ministerial Committee on Acid Mine Drainage. Council for Geoscience. December 2010, 128 pp.
4: Seath, S.G. and van Niekerk, J.A. Due Diligence Report: Witwatersrand Gold Fields Acid Mine Drainage (Phase 1). Report compiled by BKS (Pty) Ltd in association with Golder Associates on behalf of Trans Caledon Tunnel Authority (TCTA). 126 pp.
5: DWA AMD FS 2012, Study Report No. 5: Technical Prefeasibility Report

Table 7.16: Central Basin Critical Levels

Level (m amsl)	Level (m amsl)	DRD Circular		DRD No. 6 Shaft		Gold Reef City		SWV		Cinderella		ABSA tower W		ABSA tower E		Standard Bank new admin building		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 800	1 800																	
1 790																		
1 780																		
1 770																		
1 760																		
1 750	1 744.9	Surface	0															
1 740	1 740															Surface	0	Elevation as per information received from Di Duthe (Lidar Elevation).
1 730	1 739.4											Surface	0					
1 720	1 726													Surface	0			
1 720	1 720															Bottom of basement piles	20	
1 720	1 718.9											Bottom of basement piles	20.5					
1 710	1 704.9													Bottom of basement piles	21.1			
1 700	1 699.38		45.52			CM 14 Shaft Surface	0						40.02		26.62		40.62	Elevation as per information received from Di Duthe (Lidar Elevation).
1 690	1 697.74		47.16	Surface	0		1.64						41.66		28.26		42.26	Elevation as per information received from Di Duthe (Lidar Elevation).
1 680																		
1 670																		
1 660																		
1 650	1 646		98.9		51.74		53.38	SWV Surface	0				93.4		80		94	Abstraction shaft.
1 640																		
1 630	1 624		120.9		73.74	Level 2	75.38		22									Kimberley Reef Workings - Level for possible relocation of GRC museum.
1 620	1 620		124.9		77.74		79.38		26	Surface (Decant point)	0		119.4		106		120	Cinderella West Shaft - Decant Level (also the lowest point on surface in basin).
1 610																		Note: The deepest sewage infrastructure is expected to occur in the low lying areas, i.e. near the decant point. However, no information on the levels of such infrastructure could be found, but it is expected that any infrastructure deeper than 18 mbs would be affected by the water table in the aquifer before being affected by rising AMD levels.

Level (m amsl)	Level (m amsl)	DRD Circular		DRD No. 6 Shaft		Gold Reef City		SWV		Cinderella		ABSA tower W		ABSA tower E		Standard Bank new admin building		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 600	1 602		142.9		95.74		97.38		44	Water table in aquifer	18		137.4		124		138	Approximate water level of aquifer (information from the GRA 2 Report DWA (Groundwater Resource Assessment: Task 1D Groundwater Quantification.)
1 590																		
1 580																		
1 570																		
1 560	1 563		181.9		134.74		136.38		83	Bottom of weathered zone	57		176.4		163		177	Information from the GRA 2 Report DWA (Groundwater Resource Assessment: Task 1D Groundwater Quantification
1 550	1 550																	
1 540																		
1 530																		
1 520	1 520		224.9		177.74	Proposed ECL	179.38		126		100		219.4		206		220	100m below surface at Cinderella Shaft where aquifer is located
1 510																		
1 500	1 500																	
1 490																		
1 480	1 484		260.9		213.74	GRC Level 5 Museum	215.38		162		136		255.4		242		256	
1 470	1 474		270.9		223.74	Proposed SECL for GRC	225.38		172		146		265.4		252		266	10m below GRC museum
1 460	1 467		277.9		230.74	STI ECL ≡ STI TOL	232.38		179		153		272.4		259		273	17m below GRC museum
1 450	1 454		290.9		243.74	Proposed TOL	245.38		192		166		285.4		272		286	30m below Level 5 of GRC museum
1 440	1 438		306.9		259.74		261.38		208	Bottom of fractured zone	182		301.4		288		302	Information from the GRA 2 Report DWA (Groundwater Resource Assessment: Task 1D Groundwater Quantification
1 430																		
1 420																		
1 410																		
1 400	1 396		348.9		301.74		303.38	Mining Level 1	250		224		343.4		330		344	SECL for shallow mining at SWV
1 390																		
1 380																		
1 370																		
1 360																		
1 350	1 350																	
1 340																		
1 330																		
1 320																		

Level (m amsl)	Level (m amsl)	DRD Circular		DRD No. 6 Shaft		Gold Reef City		SWV		Cinderella		ABSA tower W		ABSA tower E		Standard Bank new admin building		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 310																		
1 300	1 300																	
1 290																		
1 280																		
1 270																		
1 260																		
1 250	1 246		498.9		451.74		453.38	Mining Level 2	400		374		493.4		480		494	SECL for deep mining at SWV
1 240																		
1 230																		
1 220																		
1 210																		
1 200	1 200																	

8 EASTERN BASIN

8.1 Geological Setting

The geology of the Eastern Basin differs substantially from the Western and Central basins. Here, the Witwatersrand strata form a fairly shallow, oval shaped sub-basin about 30 km long and 20 km wide in which dips of strata are relatively shallow. It is connected to the main Witwatersrand Basin in the west across a zone of steepened dip known as the Springs Monocline. Structurally, the basin is marked by prominent folding, and a number of major faults transect the area, notably the Vogel's, Jeffrey's and Grootvlei tear faults. These tear faults tend to strike E-W, while another major fault-set strikes NW-SE. Gold bearing conglomerates, which were extensively mined from surface down to depths in excess of 2 500 m, outcrop at two localities in the East Rand Basin; i.e. at the old Van Ryn and Gravelotte mines (Benoni), and again near Nigel.

The Witwatersrand rocks are almost entirely overlain by younger strata, notably the Transvaal and Karoo Supergroups, and very little of the Witwatersrand strata are exposed on surface (**Figure 8.1**). Approximately 90% of the Eastern Basin is covered by Karoo Supergroup rocks, in particular the Vryheid Formation of the Ecca Group, and the Dwyka Formation. Economic coal layers, which were mined at a number of localities, occur within some of the strata (e.g. Largo Mine). Although the Transvaal Supergroup is extensively developed it is largely covered by Karoo strata, and the Transvaal rocks (mainly the dolomite) are only exposed along river courses, especially along the Blesbokspruit.

A number of intrusive bodies occur throughout the basin. The most prominent of these are diabase and syenite dykes and sills, with a general strike of NW-SE.

8.2 Hydrogeological Setting

Figure 8.2 shows the conceptual hydrogeological model for the Eastern Basin in a cross-section from NW to SE.

The Karoo strata are susceptible to preferential weathering relative to the Transvaal or Witwatersrand strata, and shallow perched aquifers occur mainly in the sandstone and mined-out coal horizons. Clay as well as coal seams have and will be mined from Karoo sediments. Minor aquifers are associated with the weathered zone as well as the coal seams. Successful boreholes yield on average between 0.1 and 0.5 ℓ/s and are used extensively for irrigation and domestic water supplies to farmers in the area. Hydraulic interconnectivity between the Karoo and underlying Witwatersrand formations could occur via major faults/fractures and even historical exploration boreholes. Indeed indications are that some of the excavations of the Largo Colliery in the area near Marievale have collapsed and are filled with water. Water from the coal mining void probably already contributes to the total sulphate load in the Eastern Basin.

The Blesbokspruit, which flows through the Eastern Basin, has eroded through the Karoo strata and exposed the Malmani Subgroup dolomite of the Chuniespoort Group in the Transvaal Supergroup for the majority of its course. This brings the surface water in direct contact with the dolomite aquifer, improving groundwater recharge rates. The low gradient and wide ponding areas within the Blesbokspruit also contribute to accelerated groundwater recharge. Scott (1995) estimated that groundwater flows from the dolomites to underground workings represent the bulk of all water ingress to the mines. The following is relevant to the dolomite aquifer:

- Chert layers serve as barriers to trans-formational flow resulting in compartmentalisation of the dolomite aquifers;
- Compartmentalisation is created by internal impermeable boundary conditions (e.g. dykes);
- Fractures and faults provide hydraulic connection from the dolomites to the mine voids;
- Horizontal to sub-horizontal sill intrusions serve as impermeable horizons on which groundwater accumulates, limiting downward flow; and
- Vertical to sub-vertical dyke intrusions which possess some permeability along their contact margins with the host rock, allow vertical flow along these contacts, but their typically impermeable cores prevent horizontal flow across these features except where they are weathered to below the water table.

Two distinct dolomite aquifers occur within the Eastern Basin:

- In the northern part of the area, the dolomite overlies the Witwatersrand sediments where it is up to 200 m thick. A prominent set of sills, collectively referred to as the Green Sill, occur in this dolomite below 60 m. These sills have resulted in the development of a perched water table characterized by relatively shallow water levels. In spite of major fissures occurring within the dolomite allowing leakage into the mine void (particularly in the Black Reef workings), the Green Sill prevents complete dewatering of the dolomites as inflows are greater than the outflows through the sill; and
- In the south-western portion of the area, the dolomite aquifer overlies the Ventersdorp Supergroup rocks. The latter forms a hydraulic barrier between the water-bearing dolomite and the Witwatersrand sediments.

The Witwatersrand quartzite, which is not well exposed in the Eastern Basin, is not susceptible to deep weathering and therefor has low permeability, and generally only allows water through mainly via faults and fractures and along intrusive dykes.

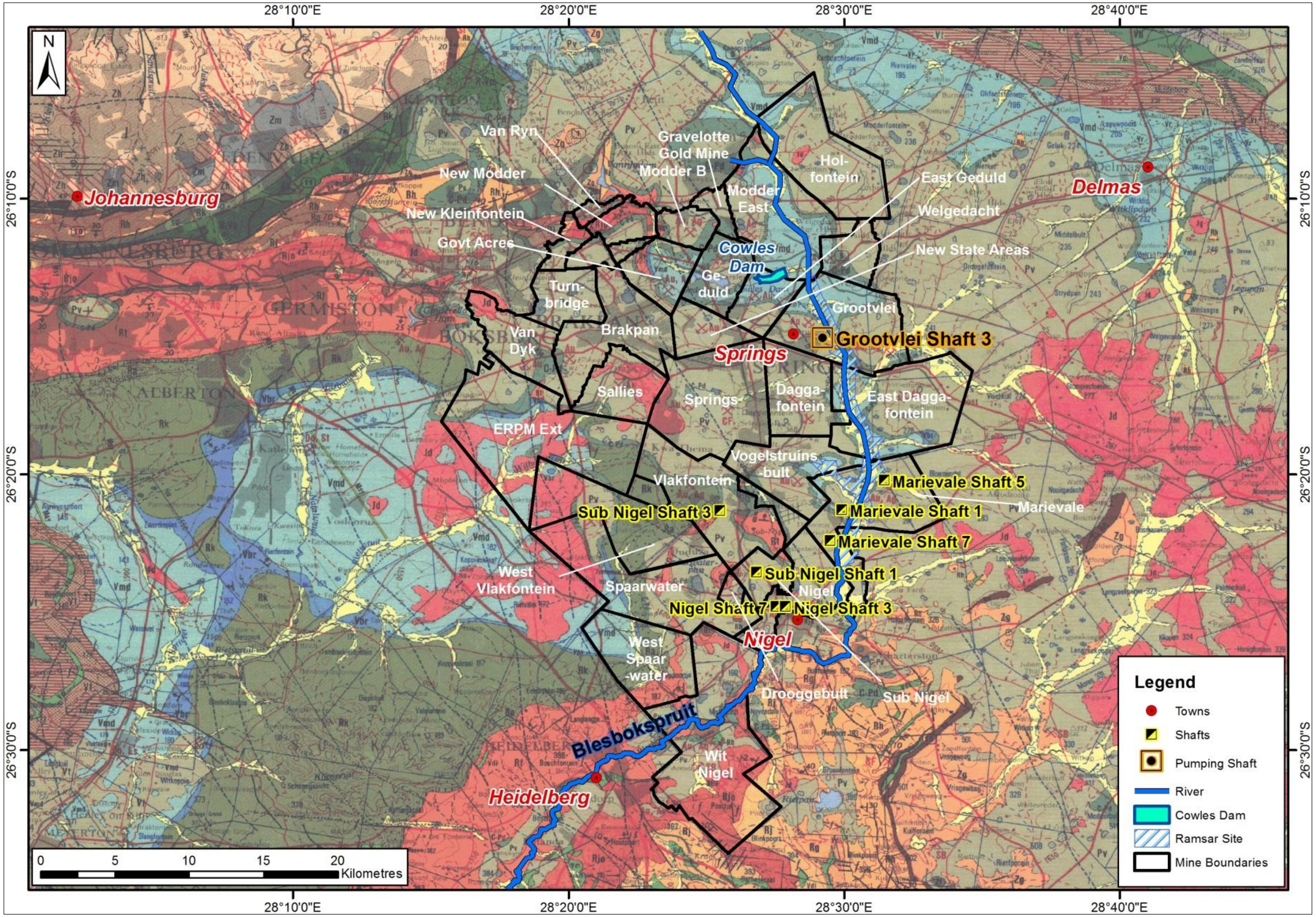


Figure 8.1: Geological map of the Eastern Basin showing mine locations and selected shafts

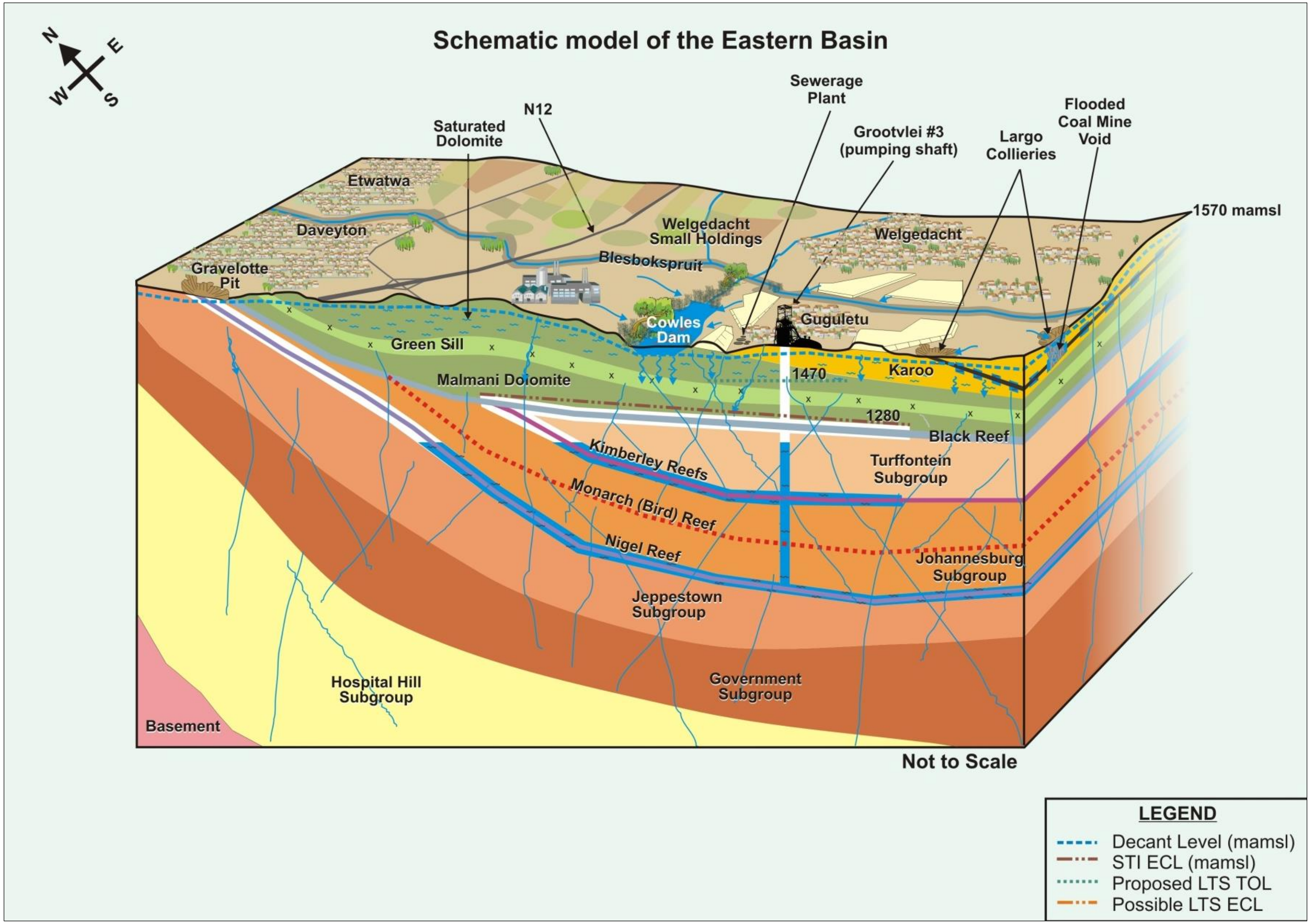


Figure 8.2: Schematic illustration of a conceptual hydrogeological model for the Eastern Basin

8.3 Mine Voids

8.3.1 History, distribution and connectivity

Gold mining in the Eastern Basin commenced soon after the discovery of gold in 1886 and peaked in the 1950s. Active mining is still taking place in the basin. In addition to gold, several coal mines operated in the area from as early as the 1890s. The last of these (Largo Colliery) closed in 1947. The main focus of gold mining was the Nigel (or Main) Reef which was extensively mined (**Figure 8.4**). The deepest workings on the Nigel Reef were located at Vlakfontein Gold Mine at a depth of about 2 300 m below surface. Of secondary importance was the Kimberley Reef where mining was more sporadic (**Table 8.4**). Limited mining was also carried out on the Black Reef.

Pumping was historically carried out from numerous locations during the peak of mining activity in the 1950s to 1960s. By the late 1970s, dewatering was only from Sallies No. 1 Shaft and Grootvlei's No. 3 and 4 Shafts (Scott, 1995). Pumping stopped at Sallies in 1991 and at Grootvlei in January 2011.

Not investigated for this study, are the isolated mining pockets in the East Rand area that do not contribute to the overall water levels in the main void. The location of these is unknown, especially to the south of the basin where the void becomes more disconnected. Holfontein Shaft to the north in the East Rand Basin may also be an un-connected mine void area (number 9 in **Appendix B**).

8.3.2 Water levels and predicted decant

Scott (1995) investigated likely surface decant points in the event of the entire void filling. The lowest shaft collar elevations occur in the southern portion of the basin because of the generally southerly slope of the land surface. The lowest shafts occur on Nigel and Sub Nigel mines (**Figure 8.3**). **Figure 8.4** shows that these mines occur in a north-westerly trending zone of more sporadic mining compared to the more extensive, continuous mining carried out to the northeast.

The dolomite aquifer is the main source of ingress (Scott, 1995) and is located above this zone of more extensive mining. The bulk of this water will need to flow across to the zone of more fragmented mining to a surface decant point on Nigel Mine. Scott (1995) investigated the interconnection between the two groups of mines, and noted that there was only limited connection. Scott (1995) identified a haulage linking the Marievale Mine (the topographically lowest mine in the area of continuous mining) to Sub Nigel (61 Level 8 haulage), and concluded that ingress water would have to flow via this route to reach the low-lying shafts on Nigel Mine. Scott (1995) concluded that this was the only link between the two mining zones. If the flow is restricted in this haulage, water from the mines in the north-eastern zone will decant at Marievale's No. 4 and 7 Shafts (1 565 and 1 564 m amsl) on surface. In the event of free flow via the haulage, surface decant will occur at Nigel No. 3 Shaft (collar elevation 1 549 m amsl estimated from a 1:10 000 orthophoto (Scott, 1995), or 1 553 m amsl according to Google Earth). This is an incline shaft that is partially filled with rubble and the roof has also collapsed. It is unlikely to be completely sealed, but the rate of flow could be reduced.

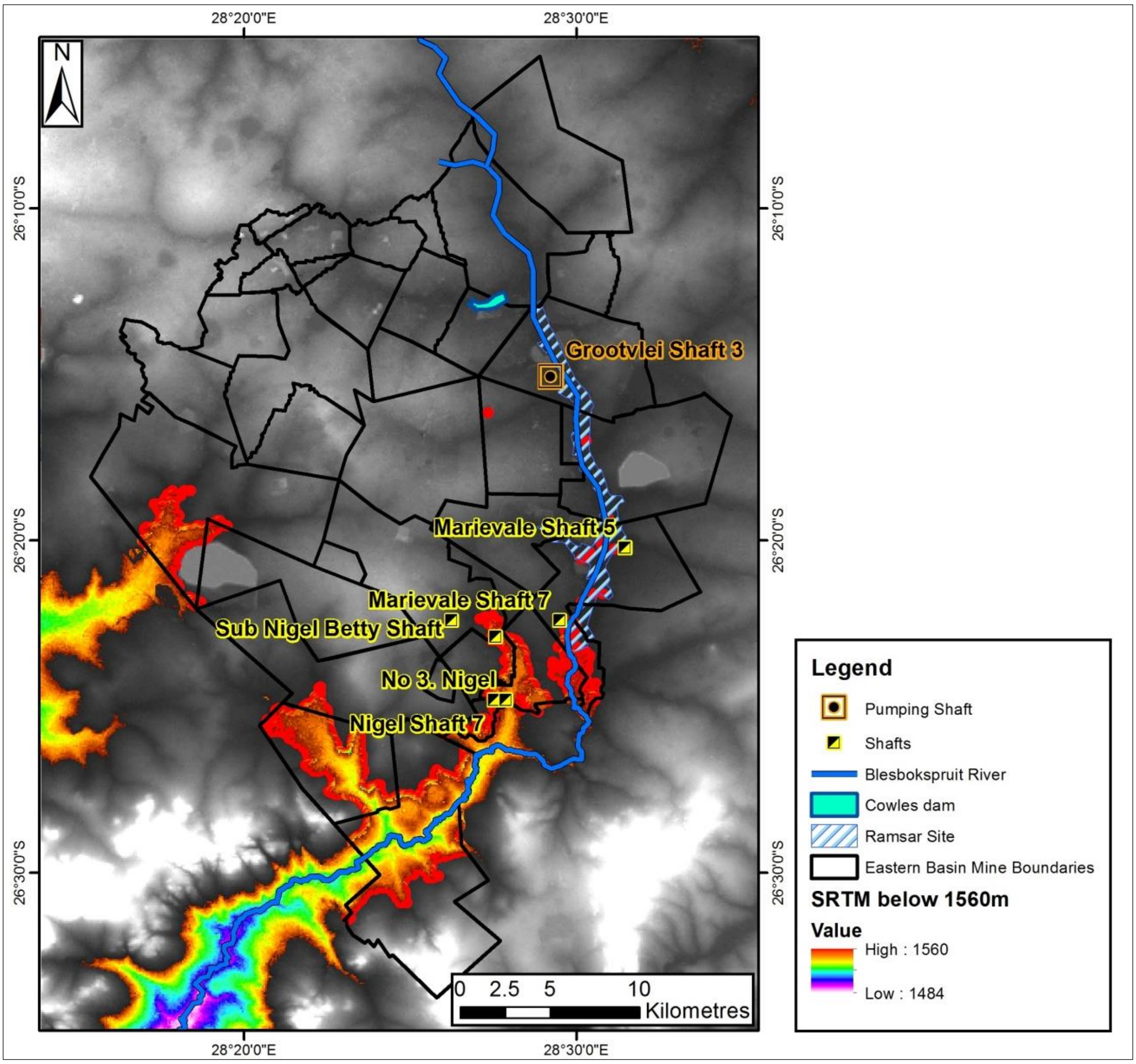
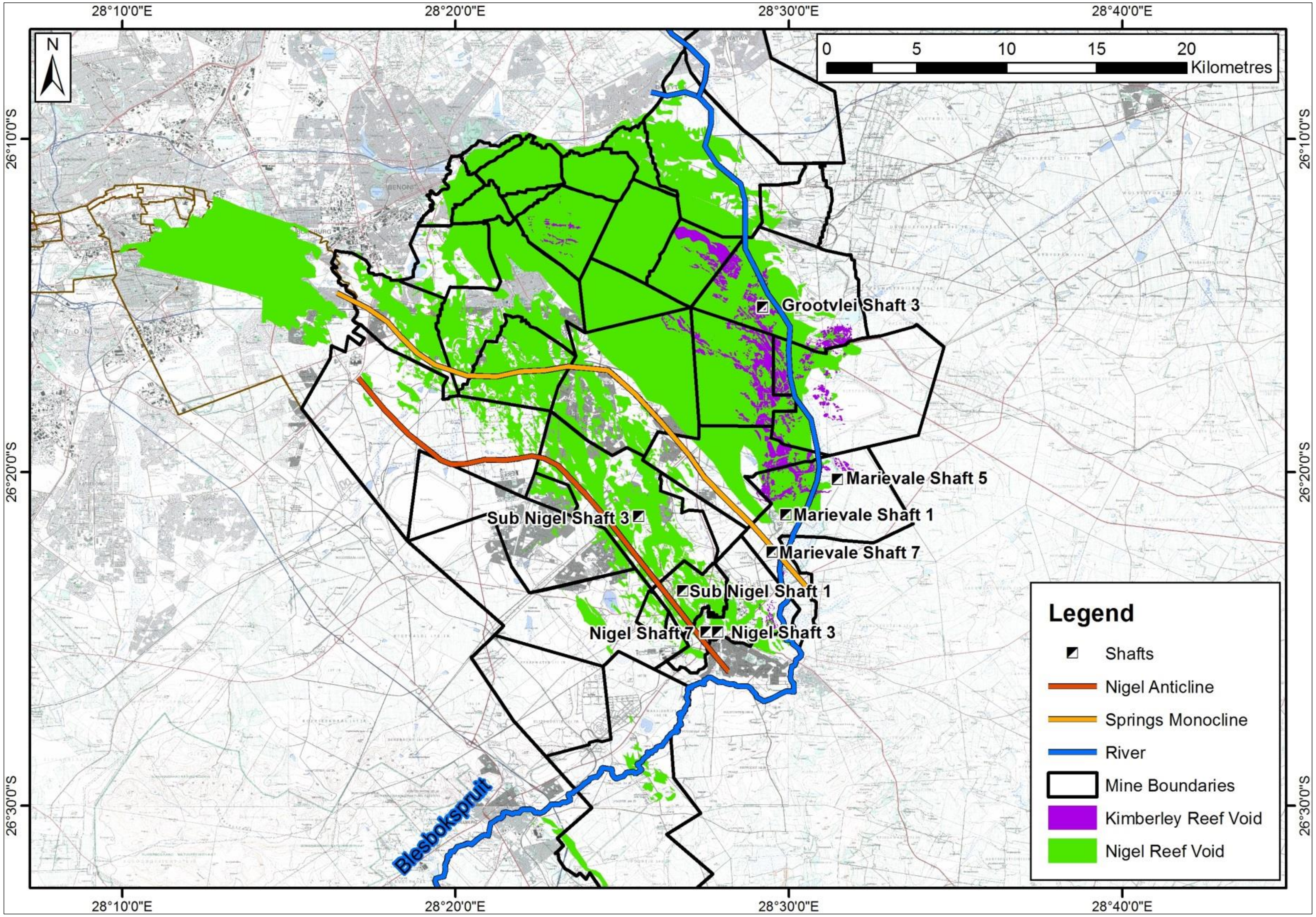


Figure 8.3: Elevations in the Eastern Basin below 1 560 m amsl defined by Shuttle Radar Topography Mission (SRTM) data



Note: The gap in the Main/Nigel Reef mine void (Boksburg Gap) between the Central Basin (Main Reef CR) and Eastern Basin.

Figure 8.4: Mine voids of the Eastern Basin with significant shafts annotated

Alternative surface decant points are Nigel's No. 2 and 10 Shafts at 1 559 m amsl, and Nigel's No. 7 and 13 and Sub Nigel B and CV Shafts, all at 1 558 m amsl (elevations estimated from 1:10 000 orthophotos). Notwithstanding the uncertainties, the linkages between the two sections of the Eastern Basin are such that the water level in the south-western portion has been effectively controlled by the pumping at Grootvlei in the north-east. However, ingress volumes into the mines in the south-western section are probably much smaller than into the north-eastern mines, and it is uncertain if the linkages could sustain flow in the opposite direction, given its likely larger volume.

The water level as measured in the Sub-Nigel No. 1 Shaft is currently rising at approximately 0.3 to 0.4 m/d (**Figure 8.6**). The single data point, suggesting a water level decrease, is considered spurious.

The TCTA (2011) predicts that the ECL will be reached between December 2014 and May 2015.

Recent measurements in the Sub-Nigel No. 1 Shaft indicate that the water levels in the Eastern Basin reached 1 025 m amsl in April 2012 (**Figure 8.5**), and it is thus predicted that the TCTA (2011) ECL of 1 280 m amsl will be reached by middle 2014. This estimate is seen as somewhat uncertain and conservative (the given ECL will probably be reached much later) because of the expected decrease in the rate of water level rise with elevation. Again, the estimates are based on poorly-defined extrapolation from more than one data source and may be in error.

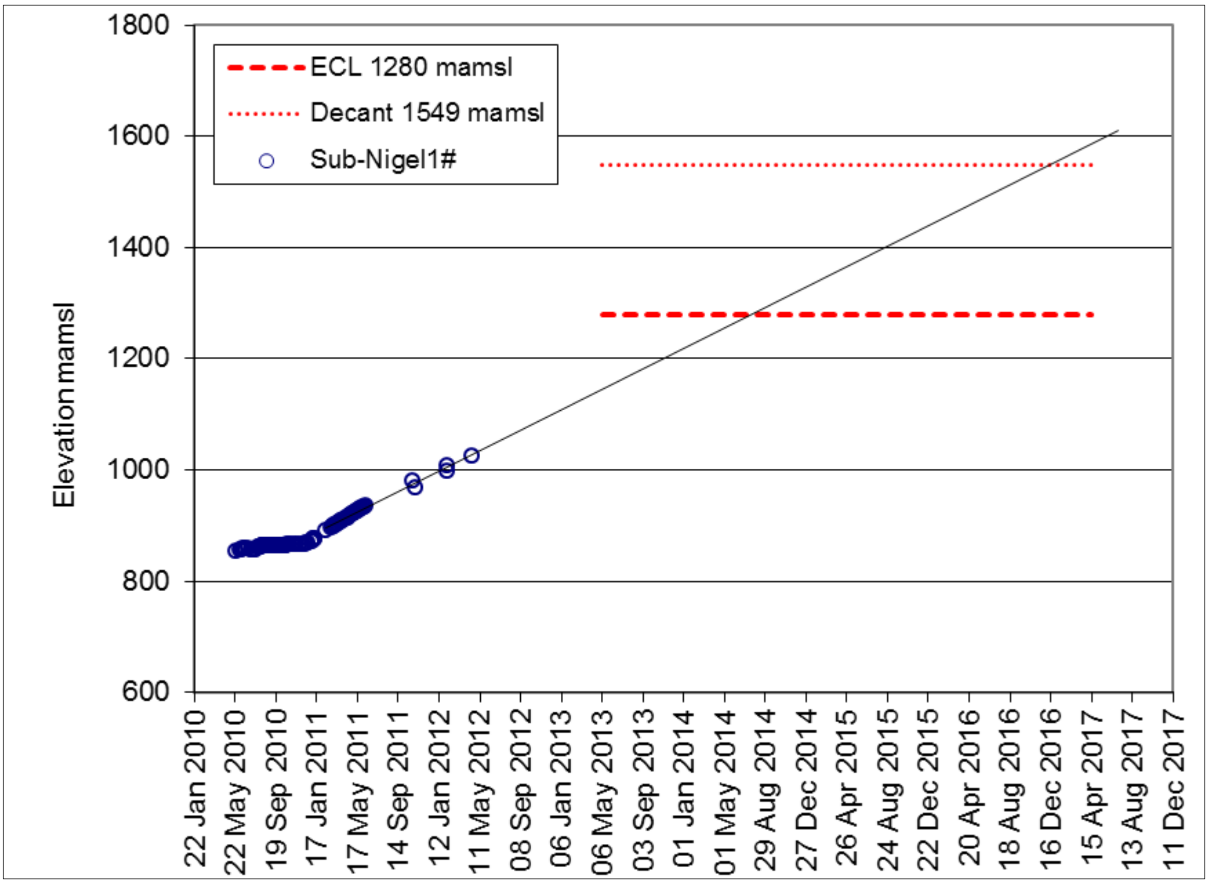


Figure 8.5: Estimated surface decant and ECL dates for the Eastern Basin

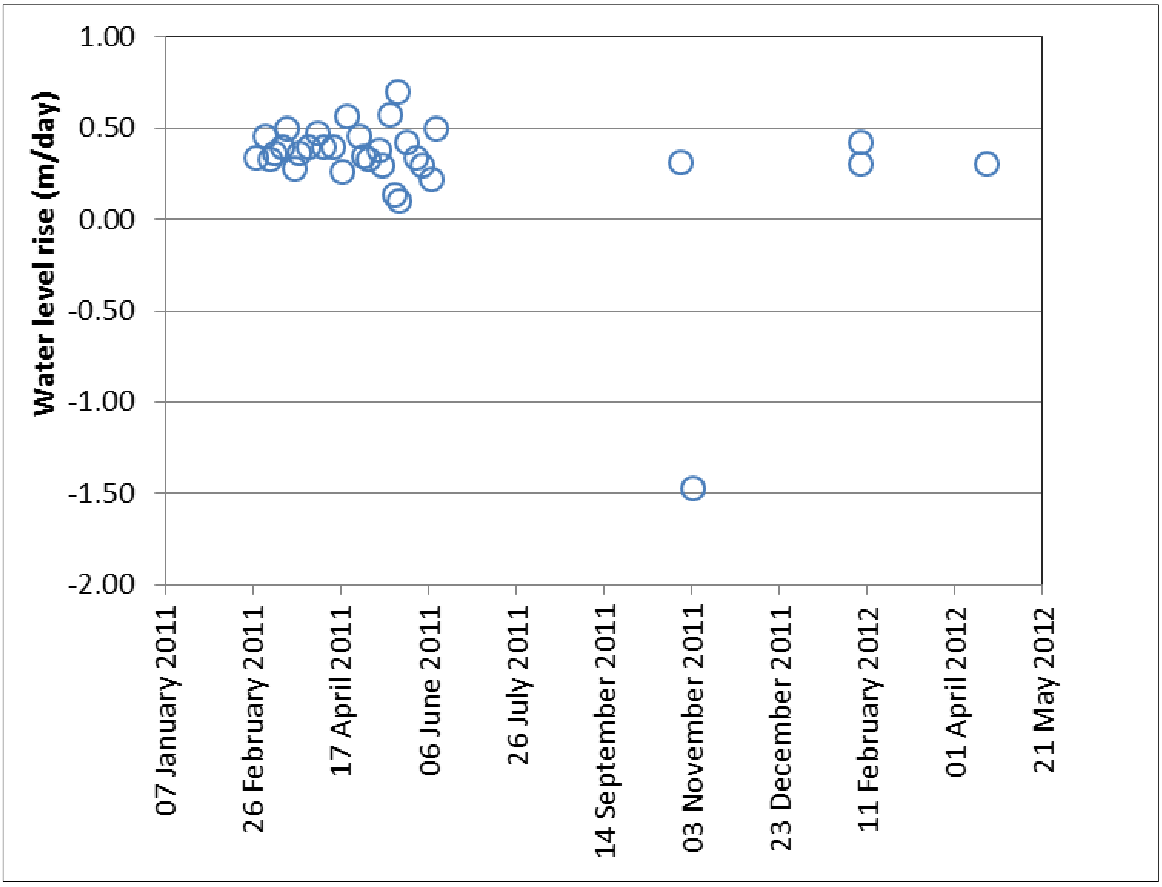


Figure 8.6: Mine water level rise in the Eastern Basin

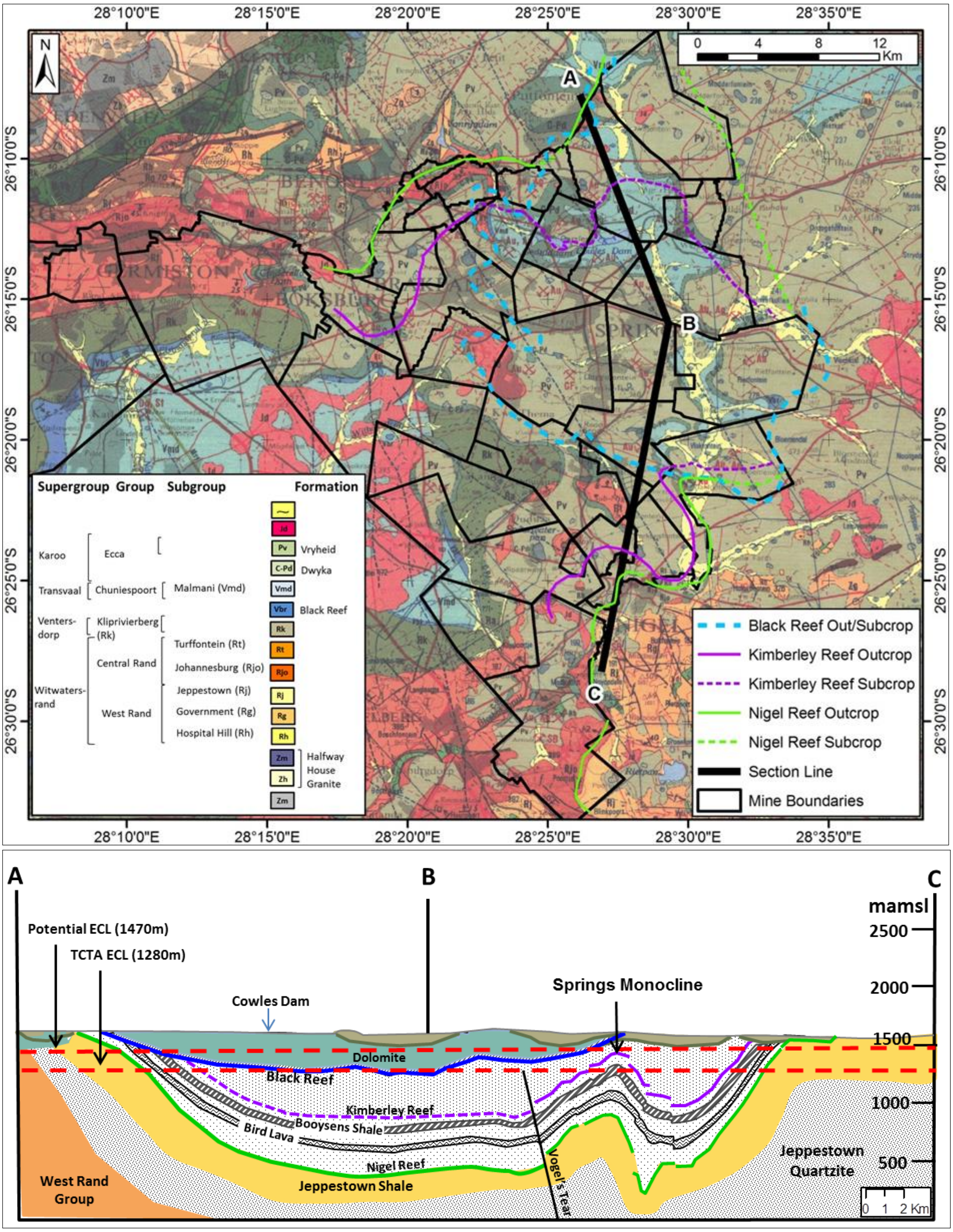
8.4 Critical Water Levels

The ECL proposed by the TCTA (2011) for the Eastern Basin is 1 280 m amsl, which was chosen to keep the water level in the mine void below the base of the dolomite of the Transvaal Supergroup. The ECL elevation would place the water level at 290 m below the collar at the pumping shaft (Grootvlei No. 3 Shaft) and about 270 m below the expected surface decant point at Nigel No. 3 Shaft. This ECL is thought to be highly conservative and could possibly be safely raised.

8.4.1 Proposed Environmental Critical Level

The dolomite aquifer is fully flooded and was so throughout the period of active mining and pumping in the Eastern Basin. The water table in the dolomite aquifer along the Blesbokspruit is at surface, which in the region of Grootvlei No. 3 Shaft is about 1 573 m amsl, and away from the river it is probably shallow (Scott (1995) notes a figure of 15 m below surface). The ECL is shown in relation to the geology in **Figure 8.7**, a cross-section aligned more or less along the Blesbokspruit, which approximates the topographically lowest portion of the basin. For the STI it is prudent to be conservative and to keep the ECL below the base of the dolomite at the TCTA proposed level. However, it should be noted that even at this ECL, deep keels of dolomite protrude through the chosen level.

An alternative is the possibility of raising the ECL to 1 470 m amsl (i.e. a depth of 100 m at Grootvlei) which would result in a substantial cost reduction. Although it does introduce a risk of mixing the dolomitic water with AMD, the shallower ECL would still be about 100 m lower than surface and thus the water table in the dolomite compartment, and it is probable that this would produce a net flow from the dolomite into the underlying Witwatersrand rocks and the mine void (**Figure 8.7**). It is recommended that the ECL of 1 280 m amsl be maintained until adequate monitoring of the water quality from boreholes in the dolomite establishes a baseline water quality. The water level can then be allowed to rise in say 20 m increments and maintained for a period of 3 months. If no change in water quality is detected, the level can be raised again. As the 1 470 m amsl is approached, 10-metre increments should be adopted. A significantly shallower ECL of 1 470 m amsl should therefore be considered under conditions of careful monitoring of water quality in boreholes at sites throughout the basin, especially along the Blesbokspruit.



Note: Showing the current ECL as per the TCTA (2011) at 1280 and potential ECL at 1 470 m

Figure 8.7: Geological plan and cross-section in the Eastern Basin in the vicinity of the Blesbokspruit

8.5 Surface Water Ingress

The northern and eastern portions of the Eastern Basin are primarily drained by the Blesbokspruit while the Rietspruit drains the central and western portions of the basin. Both rivers drain to the Vaal River.

For each of the ingress mechanisms described in **Section 4.3**, a percentage of recharge (ingress) of the rainfall and surface water runoff was estimated taking into account the existing geological formations as well as potential ingress sources to predict the expected ingress volumes into the mine workings. In addition, relevant and applicable rainfall records needed to be compiled before being able to determine the ingress volumes.

8.5.1 Meteorology

Three stations were used in the Benoni and Brakpan area (WUC, 2009). The extracted monthly average rainfall data are presented in **Table 8.1** and the annual minimum and maximum rainfall in **Table 8.2**.

In addition, an independent assessment of the average monthly rainfall, as well as possible minimum and maximum monthly rainfall, has been carried out as part of this study. Two stations, namely 0476736W and 0476766W both with 81 years of record (**Figure 4.3**), were assessed. The average monthly rainfall is summarised in **Table 8.3**.

Table 8.1: Monthly rainfall figures in the East Rand Basin

Month	Average Rainfall (mm)	Minimum Rainfall (mm)	Year Recorded	Maximum Rainfall (mm)	Year Recorded
October	74.32	15.27	1999	182.18	2001
November	111.02	10.73	1951	213.2	1998
December	117.08	37.88	1984	253.8	1949
January	131.28	55	1962	324.1	1978
February	98.25	14.8	2007	294.36	2000
March	88.68	14.32	1966	317.27	1997
April	45.64	0.53	1991	133.03	1958
May	17.85	0	Often	104.55	1997
June	7.8	0	Often	60.68	1963
July	4.59	0	Often	69.7	1957
August	6.5	0	Often	59.68	1979
September	24.13	0	1955	154.78	1987
Total	**652.82**				

Source: WUC, 2009

Table 8.2: Annual minimum and maximum rainfall figures in the East Rand Basin

Month	Driest Year - 1984 (mm)	Wettest Year - 1997 (mm)
October	81.4	41.55
November	106.08	148.05
December	37.88	104.13
January	74.2	107.58
February	23.6	64.93
March	84.34	317.27
April	10.78	27.52
May	0.58	104.55
June	6.88	8.73
July	15.4	7.63
August	0.82	5.98
September	10.72	52.47
Total	**452.68**	**990.39**

Source: WUC, 2009

Table 8.3: Average monthly rainfall data (independent rainfall station)

Month	Average Rainfall (mm)	Minimum Rainfall (mm)	Year Recorded	Maximum Rainfall (mm)	Year Recorded
October	68.7	9.05	1917	200.8	1993
November	110.1	20.1	1935	276.4	1917
December	117.4	19.15	1944	276.6	1942
January	128.9	29.5	1989	393	1977
February	100.5	23.6	1976	370.1	1943
March	92.3	7.05	1964	288.7	1924
April	44.2	0	Often	176.5	1957
May	20.7	0	Often	151.2	1935
June	7	0	Often	65.3	1988
July	7.2	0	Often	73.1	1956
August	7.1	0	Often	69.7	1978
September	25.5	0	Often	164	1986
Total	**729.6**				

The following observations derive from a comparison of the data:

- The reviewed MAP (730 mm) is similar to that of the WUC (2009) value (727 mm);
- The maximum monthly reviewed rainfall (393 mm in January 1977) is ~21% greater than the 324 mm (in January 1978) reported by WUC (2009). This could possibly be due to a more accurate and patched rainfall record used for the review study, which is based on the rainfall database used by DWA for all resource modelling (Middleton and Bailey, 2005); and
- **Figure 4.4** indicates that the expected average rainfall may increase by about 40% over the Gauteng region due to climate change. This is double the increase reflected in the

comparison of WUC (2009) and reviewed maximum monthly rainfall. Although the rainfall record of 81 years is short in meteorological time scales, climate change should still be taken into account when predicting ingress into the mine voids.

8.5.2 Review and verification of ingress volumes

A similar approach has been followed for the Eastern Basin as previously described for the Western Basin (**Section 6.5.2**) and the Central Basin (**Section 7.5.2**). Determination of the total ingress into the mine void based on water level and pumping data is described in **Section 8.5.3**.

In the Eastern Basin, mined-out reef outcrops as potential ingress sources occur to a very limited extent, whereas the dolomite aquifer above the mine void is a significant contributor to ingress into the mine void as described below.

Surface water bodies serve as additional sources of water ingress to underground works. The ingress sources are summarised in **Table 8.4**, and specific areas investigated with quantified water ingress are indicated in **Table 8.5** and shown in **Figure 8.8**.

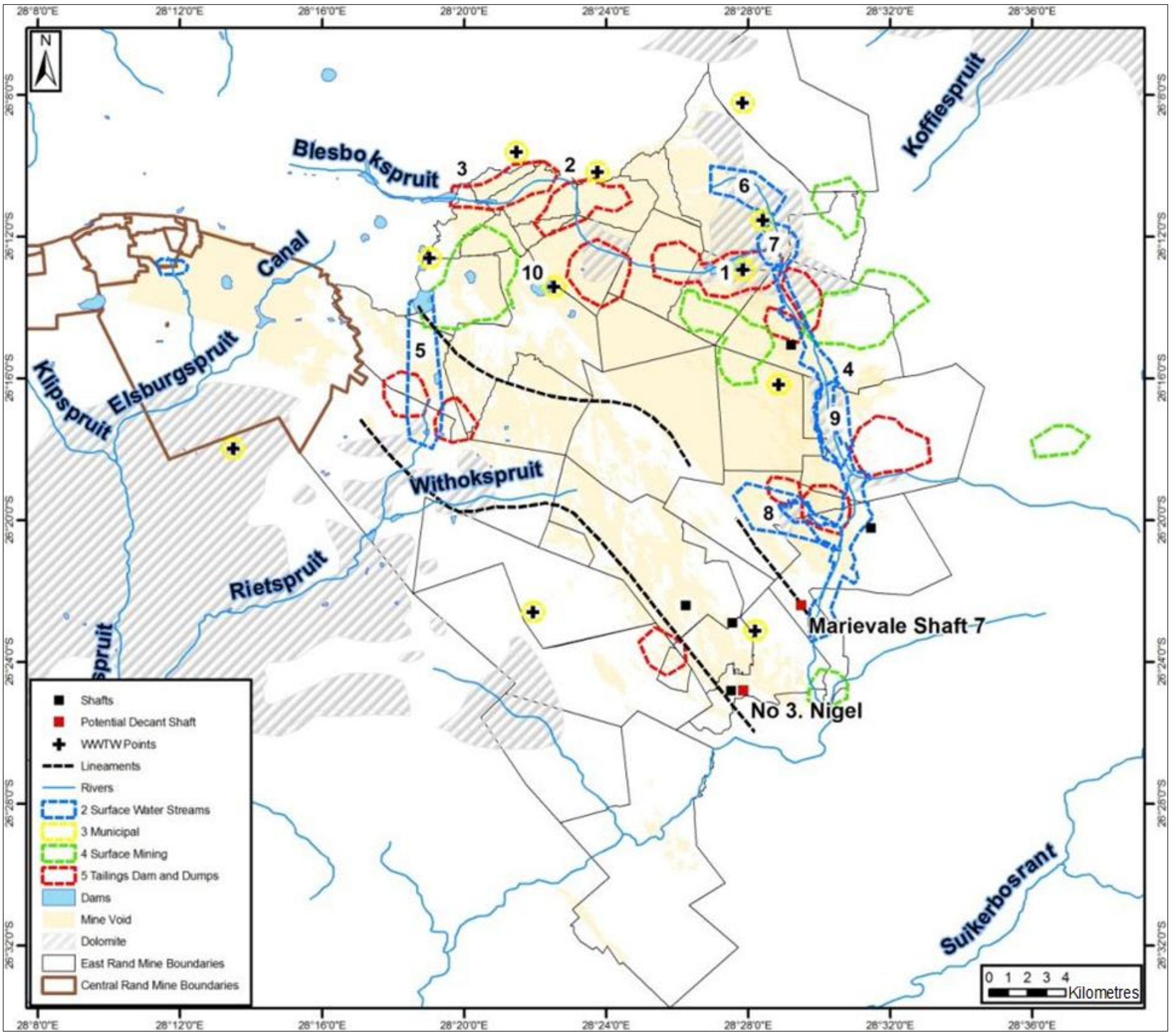
Table 8.4: Summary of ingress areas in the Eastern Basin

No.	Ingress area	Comments
1	Undisturbed geology /Shallow aquifers	Dolomite is relatively thick in this basin. The prominent Green Sill has intruded the dolomite and acts as an aquiclude, preventing dewatering of the dolomite whilst allowing accumulation of water as major reservoirs which seep into the mine workings along faults and fissures. The Modder East Dyke, and the associated faulting occurs towards the west, and is associated with high underground inflows.
2	Surface water (dams, rivers, wetlands)	Major surface water bodies e.g. Blesbokspruit and Cowles Dam are in the vicinity of major faults, dykes and opencast areas (Largo Colliery). Effluent disposal by other industries contributes a steady perennial flow of water to the dam and the Blesbokspruit system.
3	Municipal infrastructure (leaks, stormwater runoff etc.)	The upper reaches of the Eastern Basin is highly urbanised (e.g. Boksburg, Benoni) and leakage occurs from ageing infrastructure. Stormwater inflows are channelled into Leeupan (located over the Boksburg Gap).
4	Surface mine workings (open pits, shafts, inclines)	The bulk of mining was underground at depths varying from 250 m to 500 m due to poor reef exposure. West Pit and Gravelotte are surface pits that mined the reef. Largo Collieries mined the shallow coal seam and the workings are now flooded and goafing is evident in land subsidence on surface
5	Tailings dams and mine dumps	Ingress of water from mine residue deposits to the void.

Table 8.5: Water ingress zones and quantified volumes of water

Ingress Map Reference	Identified Ingress Area	Seepage to Subsurface/ Groundwater Body (Mℓ/d)
2	Leeupan	4.1
2	Cowles Dam	5.6
2	Van Rhyn	1.4
4	Gravelotte	0.2
4	Largo	0.6
2	North Blesbok (Northern Area)	1.4
2	North Blesbok (Southern Area)	0.7
2	Central Blesbok	3.9
2	South Blesbok	5.7
4	West Pit	7 - 10

Source: CGS, 2008 in preparation



Source: Modified after CGS, 2006
Note: Numbers in legend refer to source type in the preceding table

Figure 8.8: Major ingress areas in the Eastern Basin

A summary of ingress areas based on estimates from different surface sources in the Eastern Basin is given in **Table 8.5** and shown in **Figure 8.8**. Relevant data and assumptions abstracted from the WUC (2009) study, together with flow monitoring data, yield the predicted ingress volume of 82 Mℓ/d reported in **Table 8.6**. The approximate percentage distribution for each of the sources is given in **Table 8.6**.

Table 8.6: Predicted ingress volumes and sources (average rainfall)

Source	Percentage of Total Ingress volume	Expected Ingress Volume (Mℓ/d)
Dolomite aquifer seepage into mine void	42	34
Surface mine workings	16	13
Shallow undermined areas (Largo colliery)	30	25
Natural geological structures/rivers/water bodies	12	10
TOTAL	**100**	**82**

Source: WUC, 2009

In order to assess the impact of climate change on ingress volumes, the changes in rainfall reported in **Table 8.7** have been used in the predictive Goldsim Model utilised by Golder & Associates for the WUC (2009) study. A summary of the expected ingress volume variation is given in **Table 8.7**. The results indicate a significant impact. For an average change in MAP of 36%, the predicted ingress volume increases by 6%. The potential change in MAP of 20 to 40% due to climate change could increase the ingress volume by as much as 10 Mℓ/d.

Table 8.7: Rainfall variation impact on ingress volume

Rainfall	MAP (mm)	Change in MAP (%)	Predicted Ingress Mℓ/d	Change in Ingress (%)
Average	727	0.00	82	0.0
Dry Season	452	-37.83	77	-6.1
Wet Season	990	36.18	87	6.1
Extremely Wet	1 439	198.07	108	31.7
Climate Change	1 100	40	90	9.8

8.5.3 Estimations based on pumping rates and void volume

An analysis of mine pumping records carried out for the period 1952 to 1959 showed that of the 19 mines operating at that time, 12 were situated directly below dolomite outcrop and pumped 85% of the total pumped volume (Dolan, 1961, reported in Scott, 1995). Notwithstanding the extensive pumping taking place from the mine void, the shallow groundwater aquifer in the overlying rocks, including the dolomite, has remained undisturbed.

Scott (1995) has shown that recharge from rainfall directly on the exposed dolomite is sufficient to sustain the natural groundwater aquifer, notwithstanding major ingress into the mine void below. Recharge of the dolomitic aquifer also occurs via seepage from tailings dumps and this water is highly contaminated (Ntsume and McCarthy, 2005). The Blesbokspruit was originally an ephemeral stream, responding to seasonal fluctuations in the water table. However, this situation has now changed primarily due to the discharge of effluent from municipal sewage works into the creek and it is now a perennial drainage (a portion has been declared a RAMSAR site).

Scott (1995) investigated the relationship between rainfall and pumping rate from the mines and found that the correlation was extremely weak. The best correlation (0.7) was obtained by lagging the rainfall by 7 months, indicating an extremely slow response between rainfall and ingress. Scott (1995) concluded that direct recharge was a very minor contributor to total ingress, and that the large storage capacity of the dolomite aquifer strongly modulated the effect of rainfall.

Flooding of the deeper levels of the Eastern Basin commenced in August 1991 when pumping stopped at Sallies No. 1 Shaft. By August 1994, the water level had risen by 385 m, at an average of 0.34 m/d (Scott, 1995). Analysis of the rate of rise during this period showed it to be linear, which led Scott (1995) to conclude that ingress was primarily via fissures and weathered fracture zones.

Although the deeper levels (Main Reef workings) were allowed to flood, mining on the Kimberley Reef continued and a new pump station was installed at Grootvlei No. 3 Shaft, where pumping would resume once the water reached about 798 m amsl. The water level in the void was thereafter maintained at about 800 m amsl at a pumping rate of ca. 80 Mℓ/d (**Figure 8.9**). Pumping at Grootvlei finally ceased in January 2011 when the water level was at 877 m amsl at Sub-Nigel No. 1 Shaft, and the remaining void is now filling.

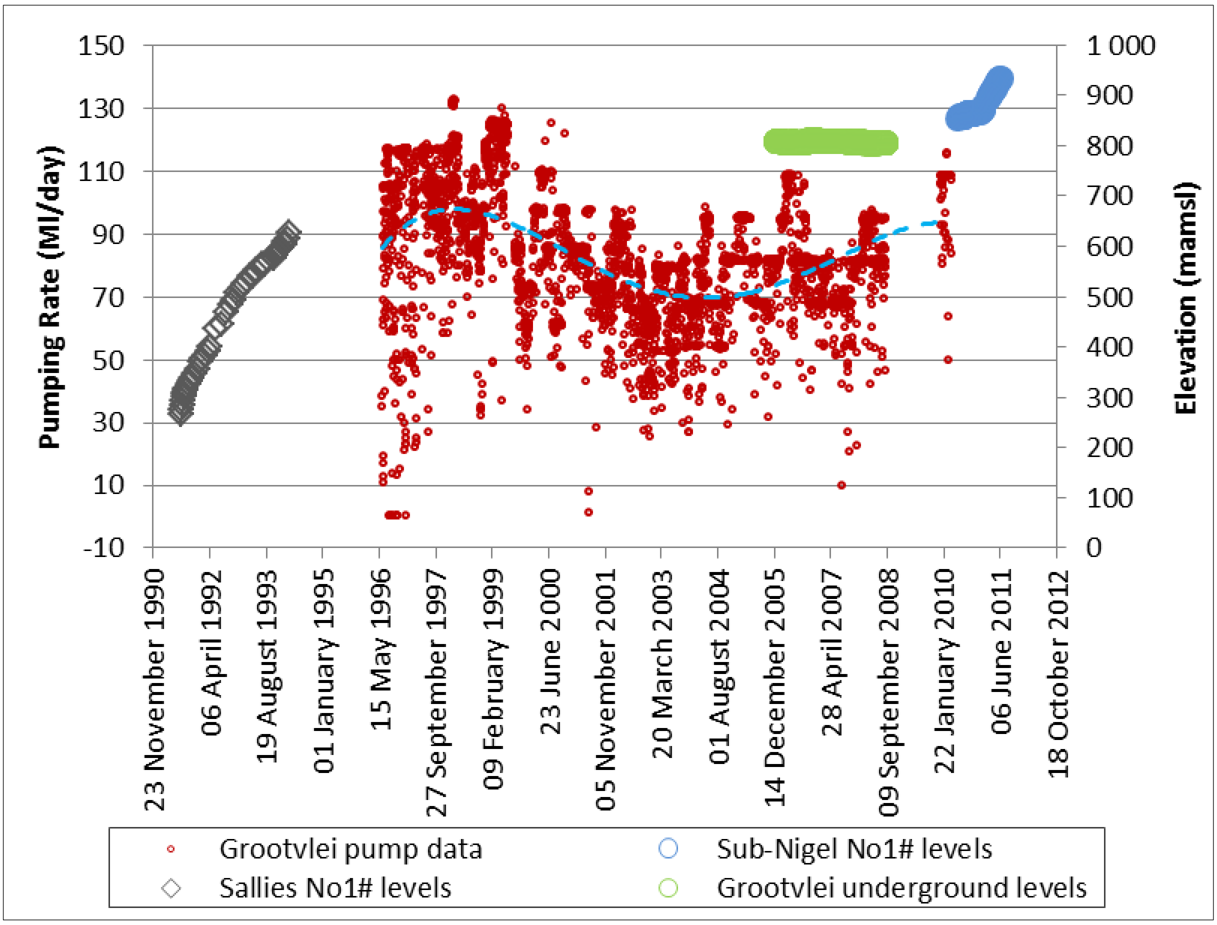


Figure 8.9: Eastern Basin pumping rates and mine water levels

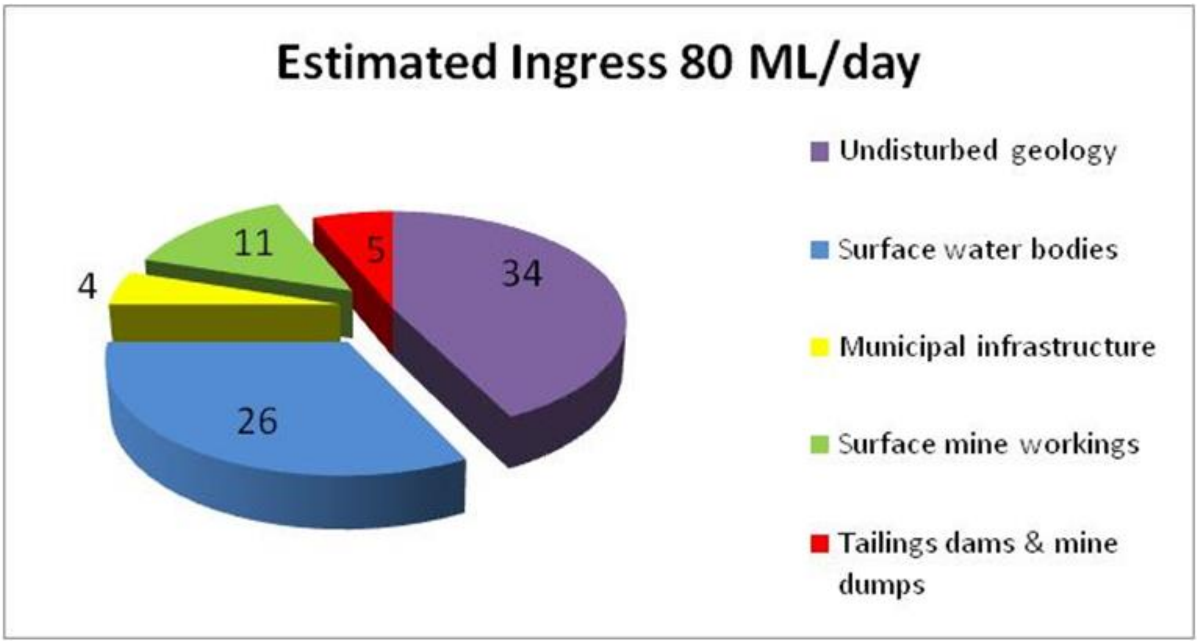
8.5.4 Minimising surface water ingress

Based on **Table 8.6**, an initial prioritisation of the main sources causing the ingress of 80 Mℓ/d into the Eastern Basin void was compiled, as shown below in **Table 8.8**.

Table 8.8: Prioritisation of ingress control measures

Source	Percentage of Total Ingress Volume	Expected Ingress Volume (Mℓ/d)	Priority of Improved Ingress Control
Undisturbed geology /dolomites (WUC)	42	34	5
Surface water (dams, rivers, wetlands) (CGS)	33	26	1
Municipal infrastructure (leaking mains and sewerage, stormwater runoff)	5	4	3
Surface mine workings (open pits, shafts, inclines) (CGS)	14	11	2
Tailings dams and mine dumps	6	5	4
Total	100	80	

Note: A priority "5" has been given to the "Dolomite aquifer seepage" and "Shallow undermined areas" as it is at this stage not known whether any practical and feasible improvements to ingress control can be used for these sources.



Note: Exploded slices indicate sources that can be controlled and fused slices sources that cannot be controlled.

Figure 8.10: The expected ingress volume for the Eastern Basin

Table 8.8 and **Figure 8.10** indicate that the majority of the inflow is from the dolomite through fractures in the Green Sill into the void, but there is no practical method for reducing these inflows. Sources of surface water ingress amount to nearly 33% of the total ingress volume, with open pits or shallow mine workings making up 14% of the total ingress. Implementing ingress control and management measures with priorities 1 to 3 (**Table 8.8**) could theoretically reduce the ingress by 42 Mℓ/d. If only half of this is achievable, ingress could still be reduced by 21 Mℓ/d by implementing methods outlined in **Section 4.3**.

Various options were identified and evaluated to prevent surface water ingress into the Eastern Basin underground workings (Mafanya and Esterhuyse, 2011). The options varied from lining the water sources (dams and spruits), to building canals and diverting culverts. The implementation of the management plans for prevention of water ingress into underground workings started in 2005 with West Pit at Grootvlei Mine, which contributed high volumes of ingress. The West Pit prevention plan model indicated that ~8 Mℓ/d of ingress could be prevented. Successful implementation of the plan has reduced ingress by ~6 Mℓ/d. The management plan required to prevent water ingress might not provide 100% prevention of ingress, but is believed to prevent large volumes of surface water (±80%) from ingressing. Despite reduced ingress volumes following the implementation of ingress control measures, surface decant is still likely once pumping ceases, as the recent 80 Mℓ/d pumped at Grootvlei substantially exceeds the volume of ingress which can realistically be prevented.

The unblocking of culverts under roads crossing the Blesbokspruit to prevent ponding of water and the consequent ingress to the underground mine void could start immediately. Other ingress prevention actions have been identified (WUC, 2009), and will require focused study and urgent implementation given that stream flows are greatly increased above their historical levels particularly because of treated sewage discharges (Scott, 1995). In the Nigel area, installing additional culverts under the R42 road should also lessen ingress.

Ingress volumes at the Cowles Dam site are similar to those recorded at West Pit (7-10 Mℓ/d). There are plans to drain the dam in order to mine the slimes, at which point flow would be diverted around Cowles Dam. This action has to be monitored in order to build up pre-engineering data to be able to determine if ingress decreases once the dam is drained.

In some areas in the Eastern Basin, the mine void is in contact with the dolomitic aquifer located immediately above the Black Reef workings. At this interface clean dolomitic groundwater has been observed flowing into the mine void. In its passage through the mine to the pumping station, this water becomes contaminated and acidic. Interception of this water via a well field or in-mine infrastructure before it becomes polluted would make a source of clean water available for use, and also reduce the volume of mine water that needs to be pumped and treated. This pumping will need to be approached with caution to prevent subsidence effects that could be triggered by dewatering of the dolomite. This option is also mentioned in the report on the regional mine closure strategies for the Eastern Basin (Mafanya and Esterhuyse, 2011), but is not recommended for implementation because of drawbacks. The latter relate to poor information on abstraction rates and costs.

Site specific control measures as recommended by Mafanya and Esterhuyse (2011) are summarised in **Table 8.9**.

Table 8.9: Site specific ingress control measures (Mafanya and Esterhuyse, 2011)

Ingress Area	Proposed Actions
West Pit	Build canal AND unblock culvert
Cowles Dam	Mine sediments and divert flow around the dam
South Blesbok	Unblock/enlarge culverts AND divert flow around certain portions – significant volume to be saved
Leeupan	Collect the grey water entering the pan and discharge it to the sewage reticulation network. Line pan. Ekurhuleni far advanced with developing the pan as nature reserve; flow diversion will nullify purpose of nature reserve
Central Blesbok	Unblock/enlarge culverts AND divert flow around certain portions – significant volume to be saved
North Blesbok (northern area)	Unblock/enlarge culverts AND divert flow around certain portions – significant volume to be saved
North Blesbok (southern area)	Unblock/enlarge culverts
Van Rhyn (ponding)	Repair channel which will drain the artificial dam
Van Rhyn (direct runoff)	Close cracks and stabilize openings
Largo	Close openings – foam
Gravelotte (opencast mine, open shaft)	Shaft closing costs low enough, costs to close opencast mine too high to be feasible. Construct upstream bunds
New Kleinfontein	Repair channel

8.6 Pumping Volumes and Abstraction Points

8.6.1 Pumping volumes required

The Eastern Basin presents a special problem in that the mine void underlies an overlying dolomite aquifer. The water resource in the latter was never significantly influenced by pumping during the mining activities, maintaining a water table close to surface in the Blesbokspruit. All indications are that water from this dolomite aquifer leaks into the mine void over a wide area, maintaining a flow of ca. 80 Mℓ/d. Pumping at this rate allowed Grootvlei Mine to maintain the water level in the mine at about 800 m amsl. It appears logical that the average pumping rate from the Eastern Basin should be ~80 Mℓ/d. Considering breakdowns and other stoppages, a pumping capacity of 100 Mℓ/d may be prudent.

8.6.2 Suitability of shafts for pumping

The TCTA (2011) reports in Appendix J that all mining at Grootvlei was carried out on the Kimberley and Nigel (Main) reefs. The intersection of the Kimberley Reef in Grootvlei No. 3 Shaft is at approximately 710 m below surface. The area around the shaft has not been mined, leaving the shaft pillar intact. A plug has been installed at approximately 790 m below surface, reducing connectivity with the Nigel Reef (the largest portion of the mine void). The Nigel Reef intersects the shaft at 1 000 m below surface, which is also the shaft bottom (personal communication Trouw, 2011).

The shaft has however proven to be connected to the entire Eastern Basin and has in the past maintained the water levels in all the sub compartments. The collar elevation of Grootvlei No. 3 Shaft is given as 1 570 m amsl by the TCTA (2011), and as 1 577 m amsl by Google Earth. This equates to a 20 m elevation difference between the lowest shaft in the greater Eastern Basin at Marievale and the pumping shaft. The cost of pumping the extra 20 m may be reduced if pumping were to take place from a lower elevation.

The Grootvlei No. 3 Shaft is also located on the Blesbokspruit wetland (**Figure 8.4**), which is a known ingress source into the mine void. The discharge of the neutralised water into the Blesbokspruit will mean that this water will be recycled and, until desalination commences, some of the salts will be returned to the void. By pumping from further south in the Eastern Basin and discharging the water downstream of the wetlands and dolomites, the potential for recycling will be reduced. This approach will increase the chances of flushing the system and improving water quality until desalination commences. Pumping from a borehole arrangement drilled into the void at the lowest elevations (rather than shafts if the shafts in this area are found to be sealed/filled or structurally not sound) will meet this objective.

The lowest level for pumping would be at the Sub Nigel Shaft. However, due to the concern that the haulage between Marievale and Sub Nigel may not be sufficient to dewater the greater Eastern Basin from Sub Nigel alone, another option would be to also use a shaft at

Marievale Mine or a borehole into the mine void. The southern portion of Marievale is also located south of the dolomite and wetlands, avoiding the return of water releases to the void.

Based on an inventory of shafts in the Eastern Basin prepared by Gold One, Marievale No. 1 Shaft was identified as having potential (**Figure 8.4**). A visit to the mine to meet Mr Herbie Trouw, an employee of Gold One who has an intimate knowledge of the East Rand Basin, was arranged. He provided additional information on No. 1 Shaft and moreover suggested that No. 5 Shaft could be a suitable alternative (**Figure 8.11** and **Figure 8.12**).

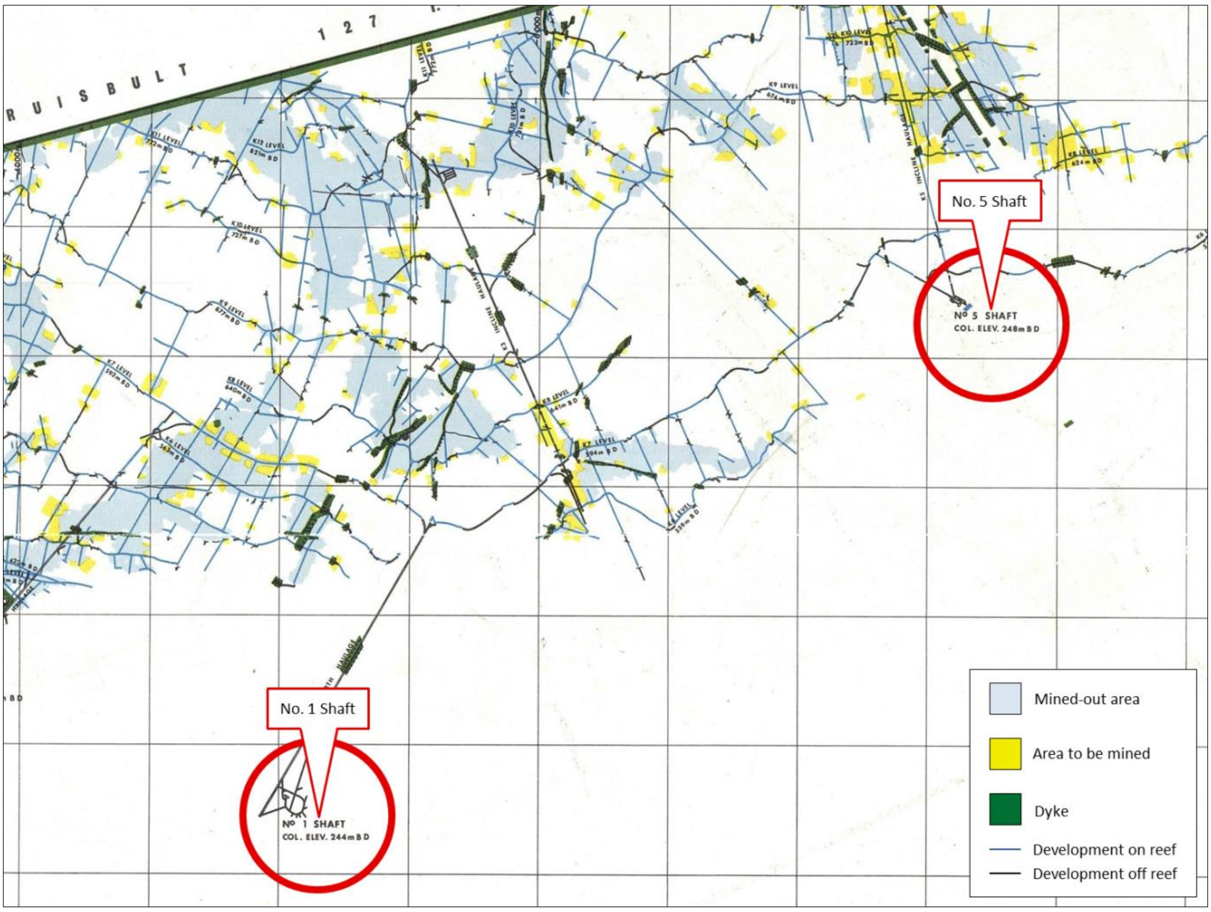


Figure 8.11: Extract from the shareholders plan showing the connection of Marievale 1 and 5 Shafts to the Kimberley Reef void

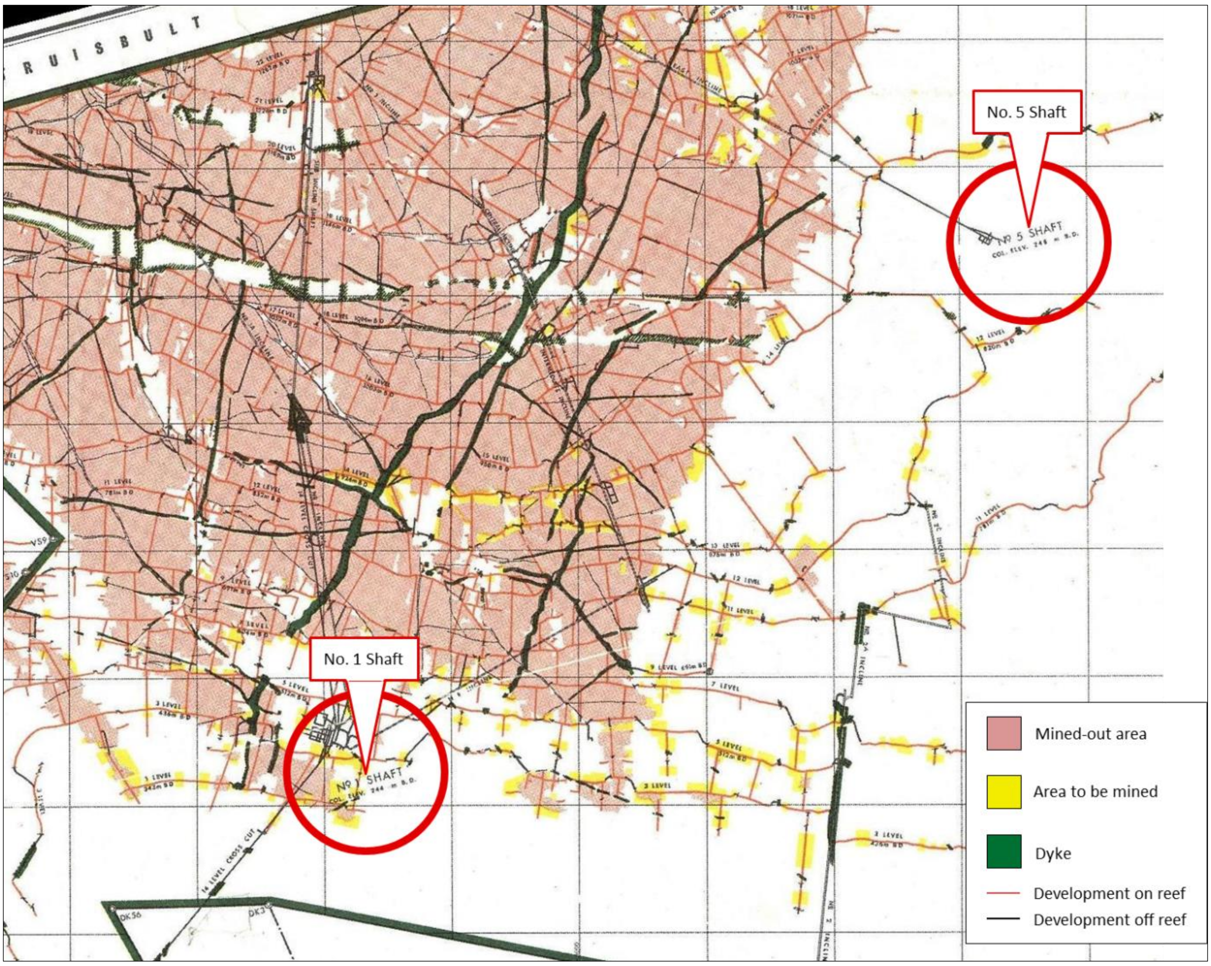
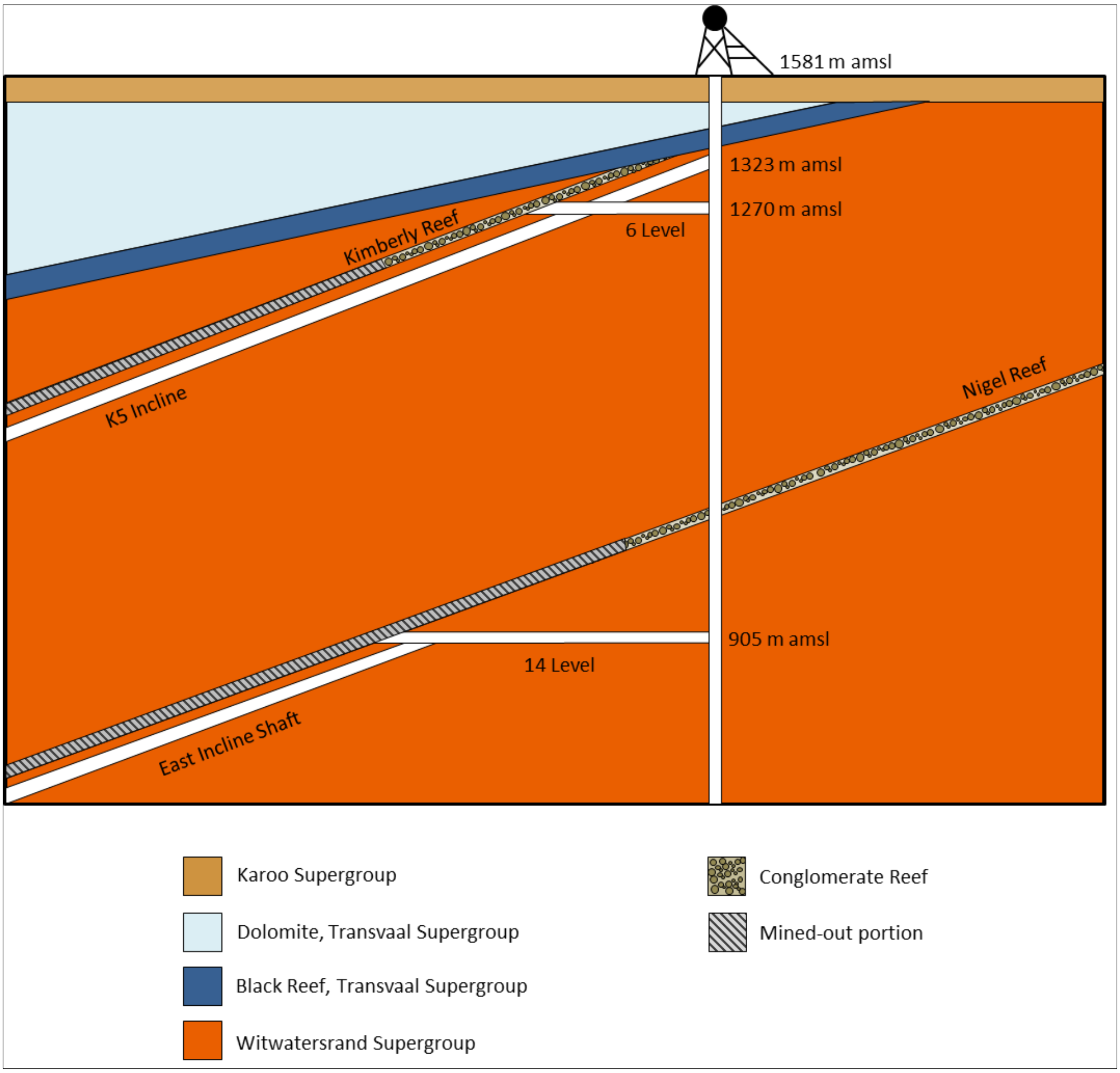


Figure 8.12: Extract from the shareholder's plan showing the connection of Marievale 1 and 5 Shafts to the Nigel Reef void

Marievale No. 1 Shaft is well connected to the void, and had been used as a ventilation shaft until mining in the Eastern Basin ceased in 2011 (H Trouw, personal communication). However, Mr Trouw informed the writers that there was some evidence of collapse in the shaft and a full shaft inspection would be necessary. Although open, the collar area was in poor condition.

A video camera investigation was subsequently commissioned by TCTA and carried out by Mine Rescue Services. The survey found that the shaft was totally blocked with steel pipes at a depth of about 190 metres below surface (Stuart Seath, personal communication to Andrew Tanner).

Marievale No. 5 Shaft (collar elevation 1 581 m amsl, mine plan) is connected to the Nigel Reef void via a tunnel on 14 Level (approximately 905 m amsl) and to the Kimberley Reef by a tunnel on 6 Level (approximately 1 270 m amsl), and an incline shaft (approximately 1 323 m amsl) on 5 level (**Figure 8.11** and **Figure 8.12**).

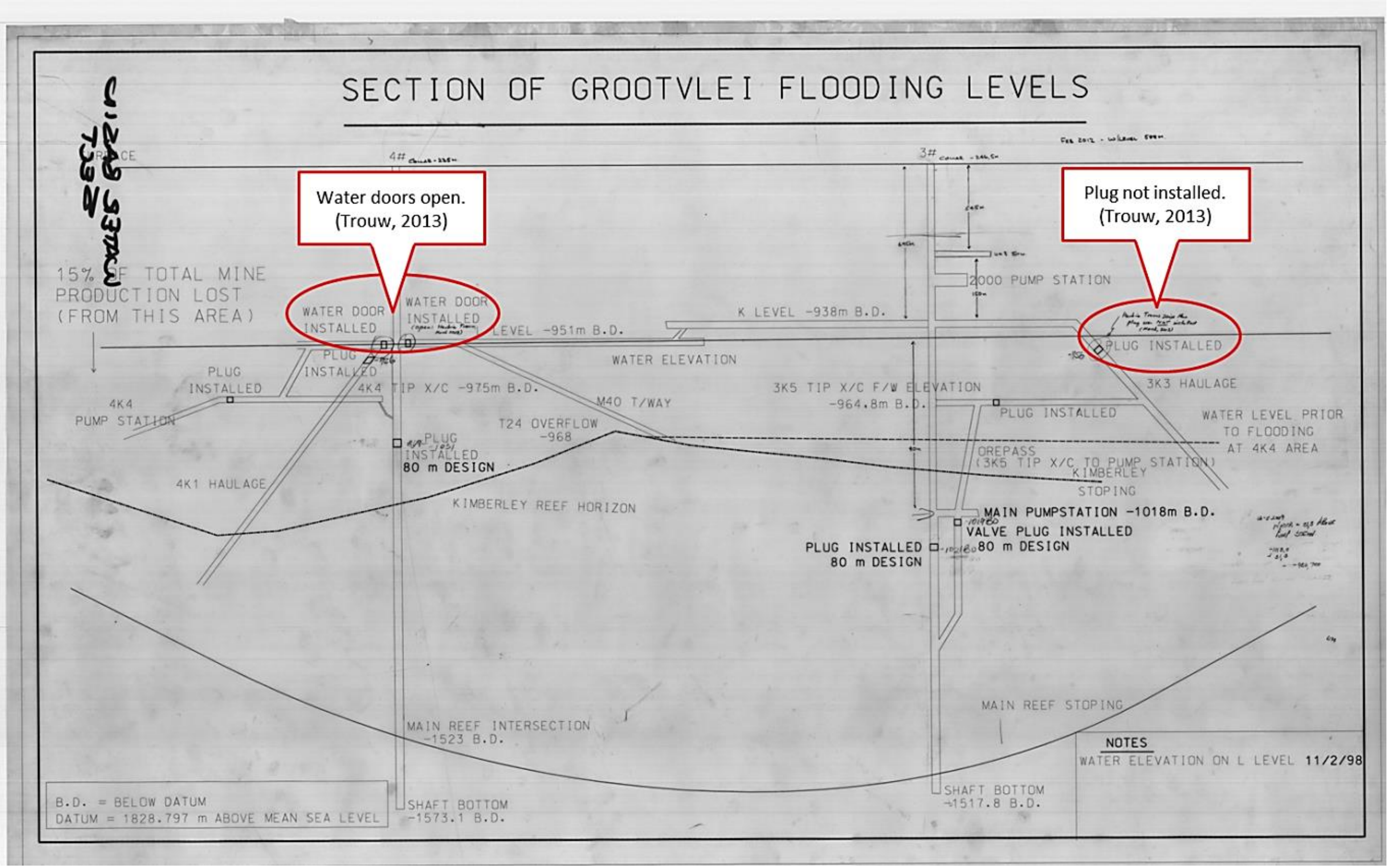


Note: Elevations taken from mine plan

Figure 8.13: Schematic cross-section through Marievale No. 5 Shaft showing connections to the mine voids

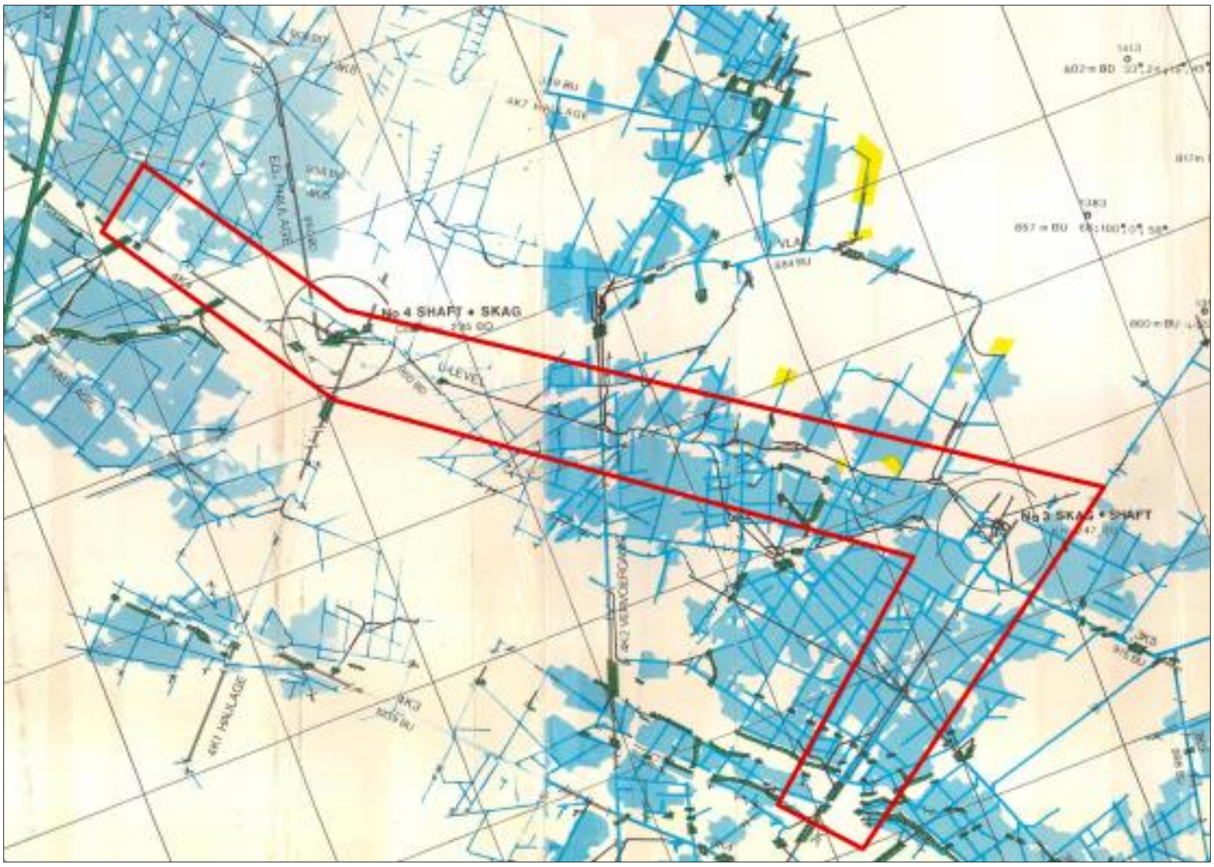
This shaft had been capped with a concrete slab. The video camera survey of the shaft by Mine Rescue Services revealed that the shaft barrel is in excellent condition. The survey found station platforms at 350 metres (possibly 6 Level, **Figure 8.4**), 386 m and 400 m below surface. The latter two may be stations that were cut but not subsequently used. The platform of the station at 400 m protruded into the shaft and the camera was not able to survey beyond this depth. In view of the looming deadline for TCTA to call for tenders, it was decided not to undertake any further survey work and to proceed with the development of Grootvlei No. 3 Shaft as the pumping site (Stuart Seath, personal communication to Andrew Tanner). Although the shaft was only inspected to a depth of 400 m, this corresponds to an elevation of 1 181 m amsl, which is 99 m deeper than the ECL set by the TCTA for the Eastern Basin. This shaft remains a possible site for future pumping activities.

In view of the decision to proceed with the development of Grootvlei No. 3 Shaft, further investigation as to its long term suitability was undertaken. This shaft is located in the eastern portion of the basin in which the Nigel Reef was extensively mined (**Figure 8.4**). Although formerly well connected to both the Kimberly and Nigel Reefs, this and the adjacent No. 4 Shaft were plugged below L level (878 m amsl) (**Figure 8.14**) thus isolating the shafts from direct connection to the Nigel Reef void. However, the shaft remains connected to this void via the widespread network of tunnels and shafts on the two reefs. This connection between the shaft and the Nigel Reef mine void has been confirmed by the fact that pumping carried out by Grootvlei Mine prior to its closure in 2011 was able to control the water level in the Nigel Reef mine void throughout the basin.



Note: Provided by Mr. Herbie Trouw. Location of the section shown in Figure 8.15

Figure 8.14: Cross section of Grootvlei No. 3 and 4 Shafts



Note: Location of the cross-section in Figure 8.14 indicated on this figure.

Figure 8.15: Shareholders plan of the Kimberley Reef workings on Grootvlei

A large proportion of the ingress into the Eastern Basin is believed to occur via the dolomite inlier situated along the Blesbokspruit (**Figure 8.1**) which hosts an extensive shallow aquifer. Ingress from this aquifer into the mine voids below is believed to be retarded and dispersed by the green sill, an igneous intrusion in the dolomite (**Figure 8.2**). The Kimberley Reef has been fairly extensively mined in the region directly below the Blesbokspruit (**Figure 8.4**) and it is probable that this void therefore intercepts much of the ingress. Grootvlei No. 3 Shaft is well located to extract water from the Kimberley Reef that lies at a shallow level and will not draw directly from the deep, highly contaminated mine void on the Nigel Reef.

Table 8.10 provides a comparison of the suitability Grootvlei No. 3 Shaft and Marievale No. 5 Shaft as pumping shafts. On balance, Grootvlei No. 3 Shaft is superior to Marievale No. 5 Shaft.

Table 8.10: Comparison of Grootvlei No. 3 Shaft and Marievale No. 5 Shaft

Shaft	For	Against
Grootvlei No. 3	Although there are plugs in the shaft and adjacent tunnels, these were placed in the shaft area to protect the pumping station. The water level is now well above the plugs and connectivity to both the Nigel and Kimberley Reef voids is good.	Eskom has removed all the power supply and totally stripped the sub-station.
	The condition of the shaft is good.	The liquidators have awarded a tender to remove all surface structures including the headgear, offices, etc.
	Pumping from this shaft enabled the water level in the entire basin to be controlled.	The discharge is onto a dolomite substrate resulting in pumped water re-charging the void. This has the effected of recycling the salts, retarding the flushing of the void.
	Pumping from this shaft encourages shallow abstraction and will promote stratification of water in the void.	Limited space for treatment plant as the shaft is very close to the 100 year flood line.
Marievale No. 5	Connectivity to both Nigel and Kimberley Reef voids is good.	To discharge partially treated water south of the weir at the Marievale Bird Sanctuary would require a 3.5 km pipeline.
	The shaft is in good condition and is securely capped.	Sludge will have to be pumped across the Blesbokspruit to suitable disposal sites.
	An Eskom sub-station is close by.	The shaft lies at the southern end of the basin and therefore will draw water through the entire basin.
	The closest discharge distance to the wetland is 1 km to the west and onto Karoo rocks which will prevent ingress of treated water and hence recycling of salts.	It is directly connected to the Nigel Reef void and will therefore draw water from deep levels.
	There is sufficient space for a treatment plant and other necessary infrastructure.	

8.6.3 Alternative options to pumping

The topography of the Eastern Basin does not favour passive solutions such as allowing natural surface decant at preferred ECLs. A tunnel length of more than 30 km would be required, which is prohibited by time and cost.

8.7 Water Qualities

8.7.1 Data Utilised

The bulk of the Eastern Basin water quality data were collected at Grootvlei No. 3 Shaft between 1997 and 2008. Water quality data was synthesised from two principal sources:

a) Surface sampling:

These samples were collected from a flume at Grootvlei No. 3 Shaft after treatment at a HDS plant and prior to discharge into the Blesbokspruit.

b) Underground sampling:

The majority of raw mine water samples are from Grootvlei No. 3 Shaft itself. The remaining underground samples were collected on behalf of the CGS from various locations in the East Geduld, Geduld and Government Areas Gold Mines.

Table 8.11: Water quality sampling data utilised in the Eastern Basin

Mine	Location	Sampling Type	Source	n
East Geduld	Various	Underground	CGS	12
Geduld	Various	Underground	CGS	11
Government Areas	Various	Underground	CGS	12
Grootvlei	Various	Underground	CGS	4
Grootvlei	Underground, pre-treatment	Underground	Irene Lea,Grootvlei	127
Grootvlei	Flume, treated discharge	Surface sample	Irene Lea, Grootvlei	3 497

n – Number of samples

8.7.2 Water chemistry

The water quality of the Eastern Basin is summarised in **Table 8.12** to **Table 8.16**. Compared to the water of the Central Basin, the water is more neutral with notably higher Mn concentrations. The buffering effect of the dolomite is evident.

Table 8.14 presents the summarised compositional ranges of underground samples only (as described in **Section 8.7.1**), can therefore be considered as a reasonable approximation for the water qualities anticipated during pumping from the mine void.

Table 8.15 and **Table 8.16** present raw water and HDS treated discharge qualities, respectively, from Grootvlei No. 3 Shaft (I Lea, personal communication, 2011), the proposed abstraction point for the STI (TCTA, 2009).

Table 8.12: Water quality (95th percentiles) of selected sites in the Eastern Basin

Parameter	Units	Mine and Sampling point					
		East Geduld	Geduld	Govt Acres	Grootvlei	Grootvlei	Grootvlei
		GH Series	GH Series	Gh1	Underground	AD/GH Series	Flume
Temp	^oC	20.1	18.2	17.3	25.0	19.5	-
pH*		7.3	6.9	2.6	5.9	6.7	7.2
EC	mS/m	299	617	395	363	227	367
TDS**	mg/ℓ	2 126	1 462	4 777	3 968	1 818	3 402
Alkalinity	mg/ℓ $CaCO_3$	223	885	195	364	181	-
Dissolved Oxygen	mg/ℓ	-	-	-	3	-	-
Salinity***	mg/ℓ	2	3	2	-	1	-
Li	mg/ℓ	0.045	0.011	0.256	-	0.134	-
B	mg/ℓ	0.126	0.476	0.719	-	1.969	-
Na	mg/ℓ	177.1	276.0	73.7	260.0	321.0	-
Mg	mg/ℓ	94.4	79.5	45.1	184.8	69.3	-
Al	mg/ℓ	0.190	0.186	61.63	0.417	2.650	-
K	mg/ℓ	5.2	5.7	6.3	-	6.5	-
Ca	mg/ℓ	-	93.5	75.3	440.0	154.6	-
Fe	mg/ℓ	0.5	0.6	53.5	248.5	2.0	1.8
Mn	mg/ℓ	0.568	0.178	7.422	6.000	0.341	-
Co	mg/ℓ	0.301	0.027	1.906	-	0.562	-
Ni	mg/ℓ	2.301	0.416	3.407	0.433	4.413	-
Cu	mg/ℓ	0.016	0.017	0.962	-	0.034	-
Zn	mg/ℓ	1.288	0.701	5.671	-	4.927	-
Ga	mg/ℓ	0.000	0.013	0.032	-	0.069	-
As	mg/ℓ	0.121	0.063	0.179	-	0.027	-
Se	mg/ℓ	0.130	0.027	0.009	-	0.062	-
Rb	mg/ℓ	0.038	0.012	0.013	-	0.018	-
Sr	mg/ℓ	1.103	0.566	0.392	-	2.392	-
Ag	mg/ℓ	0.000	0.000	0.001	-	0.004	-
Cd	mg/ℓ	0.006	0.003	0.024	-	0.003	-
Ba	mg/ℓ	0.108	0.118	0.583	-	1.712	-
Pb	mg/ℓ	0.021	0.016	0.050	-	0.177	-
U	mg/ℓ	0.184	0.006	0.858	-	0.348	-
F	mg/ℓ	-	1.000	0.000	-	0.000	-
Cl	mg/ℓ	377	306	73	204	155	-
NO_2	mg/ℓ	7.400	0.000	0.000	-	0.000	-
Br	mg/ℓ	0.000	0.000	0.000	-	0.000	-

Parameter	Units	Mine and Sampling point					
		East Geduld	Geduld	Govt Acres	Grootvlei	Grootvlei	Grootvlei
		GH Series	GH Series	Gh1	Underground	AD/GH Series	Flume
NO_3	mg/ℓ	99	15	20	-	21	-
PO_4	mg/ℓ	61	18	14	-	14	-
SO_4	mg/ℓ	1 298	665	4 332	2 624	1 056	2 268
Total Hardness	mg/ℓ	-	-	-	1 759	-	-
Chemical Oxygen Demand	mg/ℓ O_2	-	-	-	180	-	-

*5th Percentile **As received from data source
***As received from data source; slightly at variance with estimated TDS; also applies to Tables 8.13 and 8.14.

Table 8.13: Water quality range (percentiles) of combined data for the Eastern Basin

Parameter	Unit	n	Percentiles				
			5th	10th	50th	90th	95th
T	°C	140	18.6	19.8	26.3	28.0	29.0
pH*		3 613	8.2	8.1	7.5	7.2	7.1
EC	mS/m	1 046	205	251	323	360	367
TDS	mg/ℓ	234	513	990	2 781	3 962	4 248
Alkalinity	mg/ℓ$CaCO_3$	63	1	27	168	326	541
Salinity	mg/ℓ	40	0.3	0.4	0.9	1.5	1.7
Total Hardness	mg/ℓ	23	1 481	1 500	1 655	1 749	1 759
Na	mg/ℓ	141	58	66	208	252	264
Mg	mg/ℓ	53	0	0	52	163	165
Al	mg/ℓ	81	0.05	0.07	0.2	0.8	2.4
K	mg/ℓ	40	3	3	4	6	7
Ca	mg/ℓ	63	0	0	73	406	421
Fe	mg/ℓ	3 632	0	0	1	2	3
Mn	mg/ℓ	141	0	0	3	5	6
F	mg/ℓ	40	0	0	0	0	0
Cl	mg/ℓ	141	66	73	157	205	253
NO_2	mg/ℓ	40	0	0	0	0	0.1
Br	mg/ℓ	40	0	0	0	0	0
NO_3	mg/ℓ	40	0	0	8	21	88
PO_4	mg/ℓ	40	0	0	7	14	22
SO_4	mg/ℓ	227	286	619	1 488	2 356	2 581
Li	µg/ℓ	40	3	5	16	95	144
Be	µg/ℓ	35	1	1	1	1	1
B	µg/ℓ	40	60	68	98	574	1 144
V	µg/ℓ	34	1	1	1	1	1
Cr	µg/ℓ	36	5	5	5	5	5

Parameter	Unit	n	Percentiles				
			5th	10th	50th	90th	95th
Co	µg/ℓ	40	0	0	41	401	680
Ni	µg/ℓ	63	0	0	301	1 280	2 432
Cu	µg/ℓ	40	0	0	0	49	455
Zn	µg/ℓ	40	519	521	572	3 090	4 317
Ga	µg/ℓ	40	0	0	0	21	42
As	µg/ℓ	40	0	0	0	50	109
Se	µg/ℓ	40	0	0	8	52	94
Rb	µg/ℓ	40	5	7	11	29	33
Sr	µg/ℓ	40	103	129	321	1 096	1 394
Ag	µg/ℓ	40	0.0	0.0	0.0	0.0	1.3
Cd	µg/ℓ	40	0	2	3	8	17
Ba	µg/ℓ	40	93	96	105	224	1 145
Pb	µg/ℓ	40	14	14	16	31	80
U	µg/ℓ	40	0	1	8	351	453
COD	mg/ℓ	67	11	12	32	166	180
DO	mg/ℓ	100	1	2	2	3	3
*pH in reverse order, e.g. 95th precentile is 5th percentile TDS as received from source							
n= number of samples							

Table 8.14: Expected water quality (percentiles) for the Eastern Basin

Parameter	Unit	n	Percentiles						
			5th	10th	50th	60th	75th	90th	95th
T	°C	138	19	20	27	27	28	28	29
pH		101	5.9	6.1	6.5	6.5	6.6	6.9	7.1
EC	mS/m	144	98	161	280	293	314	351	363
TDS	mg/ℓ	138	484	781	2 292	2 468	2 840	3 196	3 358
Alkalinity	mg/ℓ$CaCO_3$	61	12	32	168	187	232	327	560
Total Hardness	mg/ℓ	23	1 481	1 500	1 655	1 692	1 700	1 749	1 759
Salinity	mg/ℓ	38	0	0	1	1	1	2	2
A_Na	mg/ℓ	139	58	67	208	223	238	252	264
A_Mg	mg/ℓ	51	0	0	54	62	119	163	166
A_Al	mg/ℓ	79	0	0	0	0	0	1	2
A_K	mg/ℓ	38	3	3	4	5	5	6	7
A_Ca	mg/ℓ	61	0	0	77	129	379	407	421
A_Fe	mg/ℓ	139	0	0	74	88	126	209	227
A_Mn	mg/ℓ	139	0	0	3	3	4	5	6
A_Cl	mg/ℓ	139	66	75	157	170	184	205	254
A_NO_2	mg/ℓ	38	0	0	0	0	0	0	0
A_Br	mg/ℓ	38	0	0	0	0	0	0	0
A_NO_3	mg/ℓ	38	0	0	7	11	15	20	31
A_PO_4	mg/ℓ	38	0	0	7	8	11	15	22
A_SO_4	mg/ℓ	139	240	364	1 148	1 273	1 610	1 917	2 289
A_Li	µg/ℓ	38	4	6	17	23	39	95	147
A_B	µg/ℓ	38	64	71	98	106	125	624	1 170

Parameter	Unit	n	Percentiles						
			5th	10th	50th	60th	75th	90th	95th
A_Ni	µg/ℓ	61	0	0	302	350	515	1 318	2 553
A_Co	µg/ℓ	38	0	0	45	61	96	446	748
A_Cu	µg/ℓ	38	0	0	0	1	10	73	499
A_Zn	µg/ℓ	38	520	524	586	647	1 021	3 131	4 416
A_Ga	µg/ℓ	38	0	0	0	0	0	23	43
A_As	µg/ℓ	38	0	0	0	0	12	57	112
A_Se	µg/ℓ	38	0	0	8	13	29	56	94
A_Rb	µg/ℓ	38	5	7	11	14	20	29	33
A_Sr	µg/ℓ	38	103	157	321	383	616	1 100	1 433
A_Ag	µg/ℓ	38	0	0	0	0	0	0	1
A_Cd	µg/ℓ	38	0	2	3	3	3	9	18
A_Ba	µg/ℓ	38	93	95	105	106	108	320	1 146
A_Pb	µg/ℓ	38	14	15	16	17	18	41	83
A_U	µg/ℓ	38	1	2	10	21	92	357	470
COD	mg/ℓ	67	11	12	32	38	53	166	180
DO	mg/ℓ	100	1.3	1.8	2.4	2.5	2.6	3.1	3.4
Data rounded TDS as received from the source									

All underground data used except Grootvlei pre-Feb 1999 (due to concerns over data validity)

Table 8.15: Raw mine water (pumped at Grootvlei Mine) (Grootvlei Mine, 2012)

Parameter	Unit	Min	Max	Ave	95th %
pH	0	6	6.8	6.4	6.7
Temperature	°C	25	28	26.7	28
DO	Mg/ℓ	2	3.5	2.5	3.2
EC	mS/m	294	347	321.8	342.8
TDS	mg/ℓ	1 928	3 138	2 879	3 053
Cl	mg/ℓ	170	198	183.8	193.8
F	mg/ℓ	NA	NA	<0.2*	NA
SO_4	mg/ℓ	930	2 064	1 383	1 747
Na	mg/ℓ	187	458	240	256
Ca	mg/ℓ	385	493	422	435
Mg	mg/ℓ	170	251	197	202
Al	mg/ℓ	0.1	0.9	0.3	0.7
Fe	mg/ℓ	82	210	135	206
Mn	mg/ℓ	2.4	5.4	4.1	5
Zn	mg/ℓ	NA	NA	0.01*	NA
Ba	mg/ℓ	NA	NA	<0.001*	NA
Ni	mg/ℓ	NA	NA	<0.003*	NA
COD	mg/ℓ	12	80	35.4	80
* Not measured NA = Not available					

Table 8.16: HDS Treated Water (as discharged into the Blesbokspruit, 2002) (Grootvlei Mine, 2012)

Parameter	Unit	Min	Max	Ave	95th %	Current Permit
pH		7	7.9	7.52	7.89	6.5-8.5
Temperature	^{o}C	25	28	26.7	28	0
EC	mS/m	294	333	315	329	<400
TDS	mg/ℓ	2 472	2 653	2 518	2 601	0
DO	mg/ℓ	NA	NA	NA	NA	>9
COD	mg/ℓ	NA	NA	NA	NA	<35
Cl	mg/ℓ	179	184	181.2	184	<210
SO_4	mg/ℓ	1 306	1 688	1 499	1 688	<2 200
Na	mg/ℓ	230	244	239	243	<290
Ca	mg/ℓ	310	360	341	352	0
Mg	mg/ℓ	108	123	117	123	0
Fe	mg/ℓ	0.35	1.88	0.92	1.81	<1
Mn	mg/ℓ	0.8	1.1	1.1	1	<1
Al	mg/ℓ	NA	NA	NA	NA	0.5
Ni	mg/ℓ	0.02	0.035	0.025	0.031	0
T-Hard	mg/ℓ	1 098	1 228	1 165	1 216	0
T-Alk	mg/ℓ	120	146	137	146	0
SS	mg/ℓ	4	31	21	30	<25

Not measured DO = Dissolved Oxygen COD = Chemical Oxygen Demand

8.7.3 Change of water quality with time

Monitoring of the water quality during the pumping operation at Grootvlei Mine suggests an improvement of water quality with time. This is illustrated in **Figure 8.16** with the trends observed in pH and EC values for both the underground and flume discharge sample series. It would appear that pH has stabilised at about 7.5, and the EC at about 250 mS/m. The relatively high EC and the converging nature of the underground and flume discharge water chemistries indicate that a large proportion of the water is being recycled through the dolomite aquifer, and that a fraction of the water still derives from the gold workings. These observations, as well as the relatively large volumes of ingress from the dolomite aquifer (**Section 6.3.2**), imply that at least partial flushing of the initially-formed AMD in the mine void is possible. This depends on the successful prevention of neutralised but saline treated water recirculation.

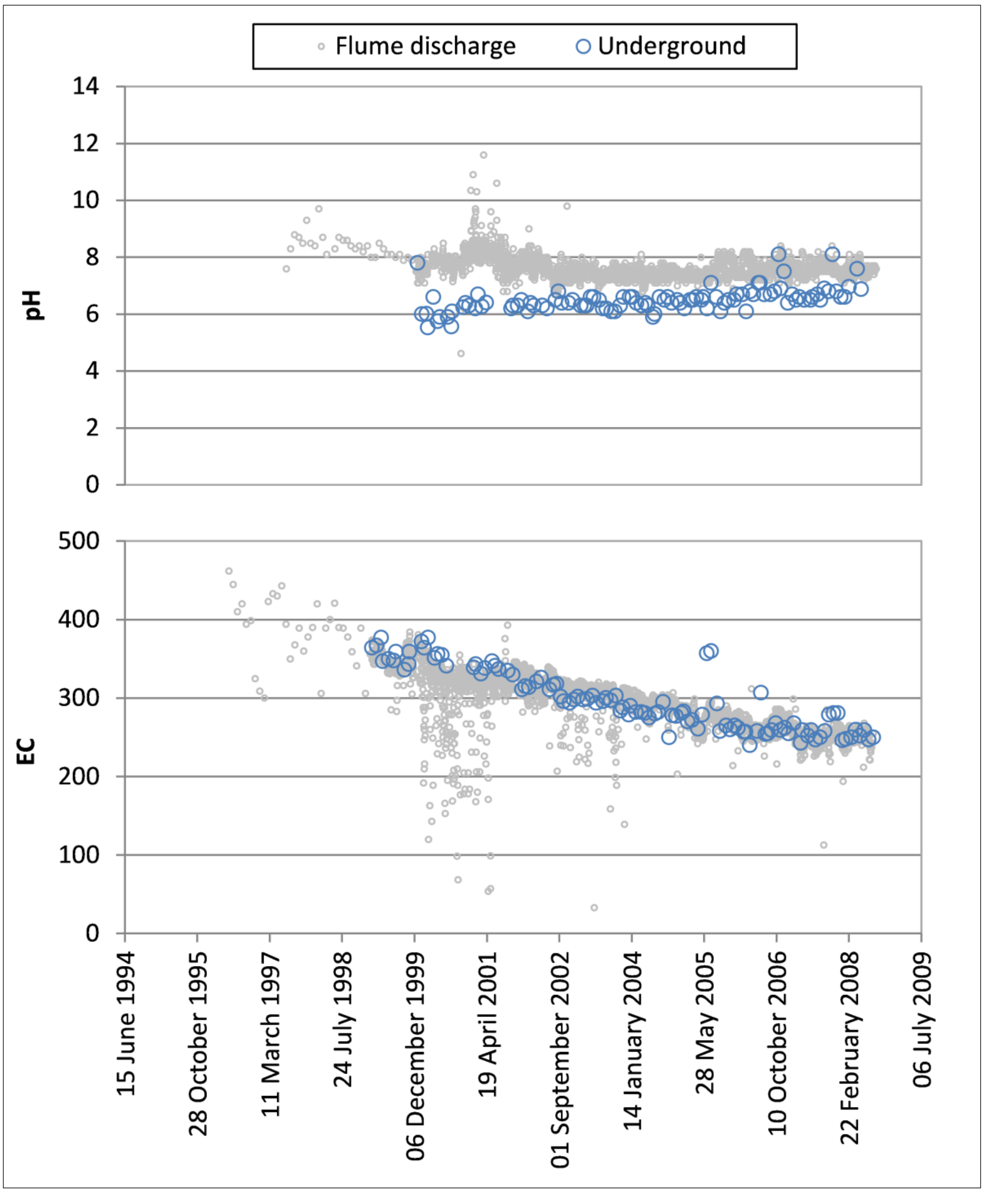


Figure 8.16: Water quality at Grootvlei Mine

8.8 Summary and Recommendations

8.8.1 Water levels and ECL

The proposed ECL of 1 280 m amsl for the STI (TCTA, 2011) is estimated in this study to be reached by middle 2014. This contrasts with the TCTA (2011) estimate of between December 2014 and May 2015. The difference may be due to extrapolation variances with limited data. The ECL is considered to be conservative, and for the STI solution it is therefore considered prudent to keep the water at this level below the base of the dolomite.

For the long-term solution, consideration should be given to raising the ECL to 1 470 m amsl under conditions of careful monitoring of water quality in surface boreholes at sites throughout the basin, especially along the Blesbokspruit. Although it introduces a risk of mixing dolomitic water with AMD, the shallower ECL would still be about 70 m lower than the water table in the dolomite aquifer. It is probable that this would produce a net flow from the dolomite into the underlying Witwatersrand rocks and the mine void.

For a detailed comparison of the important water levels chosen in this and previous reports, please refer to **Table 8.18**.

8.8.2 Ingress

The main source of ingress water is via the dolomite aquifer, especially along the zone where dolomite is exposed on surface. All indications are that water from the dolomite aquifer leaks into the mine void over a wide area, maintaining a flow of ca. 80 Mℓ/d. Because so little of the reef is exposed at outcrop, the amount of direct ingress via disturbed outcrop zones is very small.

A total ingress reduction of approximately 21 Mℓ/d is considered to be possible. This, however, needs to be studied in more detail to determine the effectiveness and financial implications. A summary of the ingress prediction and source of information is given in **Table 8.17**, with and without potential ingress control applied.

Table 8.17: Summary of predicted ingress volumes, Eastern Basin

Information Source	Predicted Ingress Volume (Mℓ/d) with no ingress control		Predicted Ingress Volume (Mℓ/d) with improved ingress control (-21 Mℓ/d)	
	Average	Range	Average	Range
WUC (2009)	82	77 - 108	61	56 - 87
This study	80	70 - 100	59	49 - 79
TCTA (planned pumping rate)	82	38 - 110	61	17 - 89

The following observations derive from **Table 8.17**:

- The estimated ingress volumes proposed in this study are in good agreement with the WUC (2009) estimations;
- The TCTA (2011) planned pumping rates compare well with the predicted range of ingress volumes and would cater both for an extremely wet season as well as expected climate change (as described in **Section 4.2**);
- Ingress volume could be reduced by a maximum of about 30 Mℓ/d if all the planned ingress control measures are implemented and are 100% effective. A more realistic figure is estimated at approximately 21 Mℓ/d, and includes the upgrade of municipal reticulation and sewerage systems and stormwater controls as Priority 3 (**Table 8.8**); and
- Control measures related to the other ingress sources have not been considered at this stage – it is assumed that these would be difficult and impractical to implement.

8.8.3 Pumping rates

Pumping at a rate of ca. 80 Mℓ/d allowed Grootvlei Mine to Stabilise the water level in the mine at about 800 m amsl. It is logical that the minimum pumping rate from the Eastern Basin should be at least 80 Mℓ/d. Considering breakdowns and other stoppages, a pump capacity of 100 Mℓ/d may be prudent.

The proven history of pumping at Grootvlei No. 3 Shaft supports its suitability as an abstraction site, despite concerns about its limited connectivity. There are concerns that the haulage between Marievale and Sub Nigel may not be sufficient to dewater the greater Eastern Basin from Sub Nigel, the lowest point. Another option would be to use the contribution of abstraction point shafts at Grootvlei or Marievale Mine and Sub Nigel Shaft or boreholes into the mine void in each sub-basin. The southern portion of Marievale is located south of the dolomite and wetlands, avoiding the return of treated water releases to the void.

8.8.4 Water quality

Compared to the water of the Central Basin, the water is more neutral to slightly alkaline with notably higher Mn concentrations. The buffering effect of the dolomite is evident, and a noted improvement of the water quality during pumping probably reflects the combined result of dilution and neutralisation by dolomite-equilibrated water. The water chemistry data from underground sampling is considered to provide the most reasonable approximation for likely water qualities to be abstracted from the mine void (**Table 8.14** and **Table 8.15**).

Table 8.18: Comparison of surface levels at key locations in the Eastern Basin

Eastern Basin - Comparison of Surface Levels at key locations and recommended ECLs, SECLs and TOLs													
Source Document	**Decant Level (m amsl)**	**Decant Point**	**ECL and SECL (m amsl)**	**Proposed Target Operating Level (m amsl)[1]**	**Depth of Proposed TOL (m) below lowest decant point**	**Rationale for Proposed TOL**	**Level not to be exceeded (e.g. bottom of aquifer)**	**Surface level at location of feature to be protected (m amsl)**	**Depth from surface at location of feature to be protected to TOL (m)**	**Other Considerations**	**Abstraction Shaft**	**Abstraction Shaft Collar Level (m amsl)**	**Depth of proposed TOL at Abstraction Shaft (m)**
IMC report (Dec 2010)[2]	1 550	Predicted decant point being within the town of Nigel	1 150	1 150	400 m below probable decant point at Nigel	Prevention of the rise of mine water into the overlying dolomitic aquifer	Not mentioned	Not given	Not given	None given	Not specified but assumed as Grootvlei No. 3 Shaft	Not given	Not given
	Not given, calculated from given ECL and depth of ECL at Nigel	Bottom of Page 25	Table 7.4, page 65	Not defined, assumed to be equal to ECL of 1 150 m amsl	Table 10.1, page 89	Table 10.1, page 89	N/A	N/A	N/A	N/A	Top of p 64 - "assistance to Grootvlei Mine should be continued to allow pumping to continue and the infrastructure to be maintained"	N/A	N/A
TCTA Due Diligence Report (2011)[3]	1 549	Nigel Shaft No. 3	1 280	1 280	269	ECL set below the base of the dolomitic formations in the Eastern Basin for protection of the dolomitic groundwater resources.	1 280	Not given	Not given	Possible mining by Gold One down to 1 040 m amsl	Grootvlei No. 3 Shaft	1 570	290
	Table 1, page 10	Table 1, page 10	Table 1, page 10	Not defined, assumed to be equal to ECL of 1 280 m amsl	Decant level minus TOL	Table 1, page 10	Annexure B: "The base of the dolomite, according to Scott (1995), is at an elevation of 1 280 m amsl"	N/A	N/A	Chapter 8.2.4, page 92	Chapter 8.3.2, page 94	Chapter 8.3.2, page 94	No. 3 Shaft Collar Level minus TOL
Long-term Solution[4]	1 549	Nigel Shaft No. 3	Conservative ECL: 1 280	Conservative TOL: 1 280	Conservative Depth: 269	Keep the water level in the mine void below the base of the dolomite of the Transvaal Supergroup.	1 280	Not given	Not given	None given	Grootvlei No. 3 Shaft	1 570	290
	This report Chapter 8		This report, Chapter 8	ECL is conservative and the TOL is also set at 1 280 m asml. (Prefeasibility Report, 1st draft, Table 2.5)	Decant level minus conservative TOL	This report Chapter 8	Level of dolomites accepted as in TCTA Due Diligence Report	N/A	N/A	N/A	Technical Prefeasibility Report, "In the Eastern Basin, consideration should be given to pumping from shafts in the south-eastern portion of the basin (Marievale) and Sub	This report Chapter 8	No. 3 Shaft Collar Level minus Conservative TOL

Eastern Basin - Comparison of Surface Levels at key locations and recommended ECLs, SECLs and TOLs

Source Document	Decant Level (m amsl)	Decant Point	ECL and SECL (m amsl)	Proposed Target Operating Level (m amsl)[1]	Depth of Proposed TOL (m) below lowest decant point	Rationale for Proposed TOL	Level not to be exceeded (e.g. bottom of aquifer)	Surface level at location of feature to be protected (m amsl)	Depth from surface at location of feature to be protected to TOL (m)	Other Considerations	Abstraction Shaft	Abstraction Shaft Collar Level (m amsl)	Depth of proposed TOL at Abstraction Shaft (m)
			Higher ECL: 1 470	Higher TOL: 1 450	Depth for Higher Level: 99	Shallower ECL would still be about 80 m lower than surface and thus the water table in the dolomite compartment and it is expected that this would produce a net flow from the dolomite into the underlying Witwatersrand rocks and the mine void.	1 470	Not given	Not given	None given	Nigel to reduce the pumping head." Thus, abstraction shaft must still be confirmed.		120
			This report, Chapter 8	20 m below ECL	Decant level minus higher TOL	This report, Chapter 8	This report, Chapter 8. "shallower ECL would still be about 100 m lower than surface and thus the water table in the dolomite compartment ".	N/A	N/A	N/A			No. 3 Shaft Collar Level minus Higher TOL

1: The "freeboard" (or buffer) proposed for the LTS, being the difference between the ECL/SECL and the TOL was estimated for the long-term for when conditions are stable. A larger freeboard would be appropriate for the short-term, until seasonal and spatial variations of the water level have been established.

2: Expert Team of the Inter-Ministerial Committee (2010) Mine water management in the Witwatersrand gold fields with special emphasis on Acid Mine Drainage. Report to the Inter-Ministerial Committee on Acid Mine Drainage. Council for Geoscience. December 2010, 128 pp.

3: Seath, S.G. and van Niekerk, J.A. Due Diligence Report: Witwatersrand Gold Fields Acid Mine Drainage (Phase 1). Report compiled by BKS (Pty) Ltd in association with Golder Associates on behalf of Trans Caledon Tunnel Authority (TCTA). 126 pp.

4: DWA AMD FS 2012, Study Report No. 5: Technical Prefeasibility Report

Table 8.19: Eastern Basin Critical Levels

Level (m amsl)	Level (m amsl)	Nigel No. 3 Shaft		Grootvlei No. 3 Shaft		Marievale No. 4 Shaft		Marievale No. 5 Shaft		Marievale. No 7 Shaft		Nigel No. 2 & 10 Shafts		Nigel no. 7 & 13, SubNigel B and CV Shafts		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 670																
1 660																
1 650																
1 640																
1 630																
1 620																
1 610																
1 600																
1 590																
1 580	1 581							Surface	0							
1 570	1 570			Abstraction Shaft Collar	0											Grootvlei No. 3 Shaft - Abstraction Shaft Collar Level
1 560	1 565					Surface	0									
1 560	1 564									Surface	0					
1 560	1 559											Surface	0			
1 550	1 558													Surface	0	
1 540	1 549	Surface (Decant point)	0													Nigel No. 3 Shaft - Decant Level
1 530																
1 520																
1 510																
1 500																
1 490																
1 480																
1 470	1 470		79	Higher ECL	100		95		111		94		89		88	
1 460																
1 450	1 450		99	Higher TOL	120		115		131		114		109		108	
1 440																
1 430																
1 420																
1 410																
1 400																
1 390																
1 380																
1 370																
1 360																
1 350																
1 340																
1 330																

Level (m amsl)	Level (m amsl)	Nigel No. 3 Shaft		Grootvlei No. 3 Shaft		Marievale No. 4 Shaft		Marievale No. 5 Shaft		Marievale. No 7 Shaft		Nigel No. 2 & 10 Shafts		Nigel no. 7 & 13, SubNigel B and CV Shafts		Comments
		Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	Feature	Depth (m)	
1 320	1 323		226		1 323		226	Connection to Kimberley Reef on level 5.	258		1 291		258		1 291	
1 310 1 300 1 290 1 280	1 280		269	Conservative ECL / TOL	290		285		301		284		279		278	Keep the water level in the mine void below the base of the dolomite of the Transvaal Supergroup.
1 270	1 270		279		1 270		279	Connection to Kimberley Reef on level 6.	311		1238		311		1 238	
1 260 1 250 1 240 1 230 1 220 1 210 1 200 1 190 1 180	1 181		368		1 181		368	Camera survey depth	400		1 149		400		1 149	
1 170 1 160 1 150	1 150		399	IMC ECL	420		415		431		414		409		408	
1 140 1 130 1 120 1 110 1 000	1 025		524		545		540		556		539		534		533	Water level April 2012

9 RISKS

Table 9.1 highlights identified risks and possible prevention and/or mitigation measures for mine water quantity and quality estimates, as well as the risks to dolomite in the region of potential AMD decant.

Table 9.1: Risk register for the hydrogeological aspects of the long-term AMD scenarios

Task / Component	Risk Description	Probability of Occurrence	Impact	Prevention Measures	Mitigation Measures
Mine Water Quantity	Unforeseen changes in the volume of the void as the water rises.	Possible	Significant	Ensure that pumping and treatment commence prior to water levels reaching ECLs.	Measure water levels across the basins.
	The degree of connectivity across the mine void in the Central Basin remains uncertain and multiple surface decant sites might occur if connectivity is not sufficient.	Possible	Severe	Allow significant freeboard initially and reduce when hydraulic gradient is stable. Implement pumping strategy at multiple sites.	Measure water levels across the basins to monitor for differential water levels. Identify suitable additional pumping sites and develop pumping strategy.
	Collapse of key water pathways in poorly connected shafts, or of the shaft itself, leads to cessation of pumping.	Unknown	Severe	Implement pumping strategy at multiple sites. Select sites with a higher level of connectivity.	Identify suitable additional pumping sites and develop pumping strategy.
	Seismic events lead to reduction of interconnectivity or damage to abstraction sites.	Possible	Severe	Implement pumping strategy at multiple sites. Select sites with a higher level of connectivity.	Monitoring of seismicity. Identify suitable additional pumping sites and develop pumping strategy.
	The timing of the water level reaching the ECL is difficult to predict, as the rate of rise in the Eastern Basin is not properly quantified because of insufficient data.	Likely	Noticeable	Ensure that pumping and treatment commence prior to water levels reaching ECLs.	Identify monitoring sites and measure water levels across the basin.

Task / Component	Risk Description	Probability of Occurrence	Impact	Prevention Measures	Mitigation Measures
	Ingress exceeds the installed pumping capacity.	Unlikely	Noticeable (EB, WB) Severe (CB)	Ensure that there is sufficient installed pumping capacity to cater for pump failures and abnormal ingress.	
	Quantity of void water exceeds the treatment capacity of the plant, leading to contamination of surface water.	Unlikely	Significant		Overflow facility.
	Mines re-started/new mines planned with own pumping strategy, resulting in possible pump/treatment plant redundancies.	Possible	Significant		Effective communication strategies between DWA, DMR and mining companies active in the Witwatersrand Basin.
Mine Water Quality	Unacceptable pollution from AMD will continue to occur because of runoff from mine dumps, etc.	Likely	Significant	Remove mine dumps to safe storage sites.	DWA to enforce control management of surface sources of AMD.
	Water contamination from industry.	Very Likely	Noticeable		Ensure this does not affect treatment plant water quality requirements.
	The rate of improvement in water quality is uncertain and quality could remain poor for a very long time.	Likely	Noticeable		Underground experiment in a previously flooded mine, where mining recommences.
	Pumping from a shaft with only deep connection to the mined area may prolong the pollution.	Likely	Noticeable	Select sites with a higher level of connectivity at shallower levels.	Identify suitable additional/alternative pumping sites and develop pumping strategy.
	When pumping commences from newly flooded, shallow levels, water quality may be worse than anticipated.	Likely	Noticeable		Design treatment for a range of water qualities that includes the poorest anticipated qualities.
	Water qualities worse than predicted due to insufficient water quality data from within the mine void.	Possible	Noticeable	Initiate water quality monitoring from multiple boreholes drilled directly into mine void.	Design treatment for a range of water qualities that includes the poorest anticipated qualities.

Task / Component	Risk Description	Probability of Occurrence	Impact	Prevention Measures	Mitigation Measures
Dolomites	Sinkholes may develop due to water table fluctuations close to the dolomite aquifer, especially in the upper reaches of the Tweelopie Spruit in the Krugersdorp Game Reserve, including the R24.	Possible	Severe		Identify and monitor existing sinkholes and carry out ground geophysical, and gravimetric surveys.
	Excessive groundwater abstraction (i.e. for irrigation) causes interaction of mine void water with dolomites in the Eastern Basin.	Unlikely	Noticeable	Maintain ECL at 1 280 m amsl (TCTA, 2011) level until monitoring established.	Monitor agricultural abstraction points.
	Sinkholes may develop due to AMD water flow through the dolomite strata.	Possible	Noticeable		Identify and monitor existing sinkholes and carry out ground geophysical and, gravimetric surveys.
	Dewatering of the dolomite outlier will result in the Hippo Dam and springs in the Krugersdorp Game Reserve drying up.	Likely	Noticeable	Maintain ECL at 1 280 m amsl (TCTA, 2011) level until monitoring established.	Monitor agricultural abstraction points. Monitor groundwater levels
Isolated mine void compartments	Reefs where limited mining took place which are isolated from the main voids, will fill as independent sub-basins	Likely	Variable, depends on decant volume	Detailed investigation into historical mining in the three basins.	Additional pump sites where necessary.

10 CONCLUSIONS

Although there are some discrepancies and differences in certain areas between this study and the TCTA (2011) assessment, the latter is considered to be broadly acceptable in terms of proposed pumping rates and water quality (**Sections 10.2** and **10.3**).

The uncertainties inherent in the data, and in particular in the detail of the void characteristics, do not allow for high accuracy predictions to be made. It is also impossible to assign any degree of confidence to the predictions made. These uncertainties will best be solved by adopting an initially conservative approach together with a well-considered monitoring program established in advance of commencement of pumping as part of the short-term intervention. Feedback from the initial operations can be used to optimise the pumping and water treatment processes.

10.1 Critical Water Levels

It is considered that pumping should occur from as shallow as possible. This will reduce pumping costs and benefit from the expected improvement of water quality over time, without placing either the environment (specifically shallow water aquifers) or certain socio-economic features (e.g. Gold Reef City museum) at unacceptable risk. The proposed ECL and SECL (**Table 10.1**) are based on this premise.

The inherent uncertainties necessitate that the ECLs/SECLs are kept under close review during pumping, and that raising or lowering of these levels be informed by suitable water quality and quantity monitoring. The SECL depends on future mining activities, and could affect the TOL in the long-term.

Table 10.1: Summary of the critical water levels proposed in this study

Basin	TCTA (2011) ECL (m amsl)*	Proposed Initial ECL (m amsl)	Possible Long-Term ECL (m amsl)	Proposed SECL (m amsl)
Western	1 550	1 600	1 565 if 1 600 does not prevent pollution	-
Central	1 467	1 520		To suit mining or 1 474
Eastern	1 280	1 280	Raise to 1 470 over time if monitoring shows no groundwater pollution	-

**The ECL proposed by the TCTA Due Diligence Report (2011) already includes a buffer and therefore the STI ECL equates to the long-term TOL.*

10.1.1 Western Basin

The Western Basin ECL is set at an elevation of 1 600 m amsl to prevent the water from the mine void entering the karst aquifer hosted by the dolomite outlier via the Black Reef mine workings at approximately 1 610 m amsl. It is proposed that the water be kept at this level for an appropriate duration to establish whether the water quality downstream improves.

If leakage of direct AMD ceases then the water could be held at this level; if not it could be lowered further, i.e. towards the 1 550 m amsl as recommended by the TCTA (2011).

No SECL is currently foreseen, although as in all three basins under consideration, there remains potential for new mining operations to become economically feasible, depending on the gold price.

10.1.2 Central Basin

The ECL is determined to be at an elevation of 1 520 m amsl. This is based on an estimated depth of 100 metres below surface at ERPM, and should adequately protect the surface aquifer.

The Gold Reef City mining museum at 1 484 m amsl in Crown Mines No. 14 Shaft was taken to be the critical factor in determining the SECL. The SECL is set at an elevation of 1 474 m amsl to accommodate the lowering of the double-decker conveyance and to ensure that the museum can still be visited as a heritage site. If this SECL is used, then the TOL must ensure that there is sufficient freeboard to allow for potential slow flow rates between this location and the abstraction site.

10.1.3 Eastern Basin

The ECL of 1 280 m amsl (TCTA, 2011) will ensure a positive downward flow from the overlying dolomite aquifer into the void, and prevent contamination of this resource. The base of the dolomite is not regular, however, and deeper keels may be present that are not well defined. Nevertheless, the risk of significant interaction with mine water is considered to be acceptable.

An alternative to this is the possibility of raising the ECL to 1 470 m amsl (i.e. a depth of 100 m at Grootvlei), which would result in a substantial cost reduction. This would still be about 70 m lower than the water table in the dolomite aquifer, and it is probable that this would still produce a net flow from the dolomite into the underlying Witwatersrand rocks and the mine void. However, this does introduce the possibility of mixing the dolomitic water with AMD, a risk that is poorly understood and not quantifiable at this stage.

It is proposed that the ECL of 1 280 m amsl be retained, but that raising the ECL under conditions of careful monitoring of water quality in boreholes at sites throughout the basin, especially along the Blesbokspruit, should be considered.

The SECL is dependent on future mining plans and cannot be defined at present.

10.2 Water Quantity

The pumping rates as derived in this study are compared with those of the TCTA (2011) in **Table 10.2**.

Table 10.2: Comparison of pumping rates

Basin	Approx. Average Pumping Rates (TCTA, 2011) (Mℓ/d)		Proposed Pump Capacity and Rate (this study) (Mℓ/d)		
	Volume	Range	Capacity	Range	Average Rate
Western	27	23 - 35	40	23 - 27	23
Central	57	34 - 84	50	46 - 50	46
Eastern	82	38 - 110	100	80 - 100	80

Table 10.3: Expected ingress volumes (without and with ingress control measures)

Western Basin				
Information Source	Predicted Ingress Volume (Mℓ/d) with no ingress control		Predicted Ingress Volume (Mℓ/d) with improved ingress control	
	Average	Range	Average	Range
WUC (2009)	18	16 - 20	13	11 - 15
This study	23	19 - 27	18	14 - 22
TCTA (2011) planned pumping rate	27	23 - 35	22	18 - 30
Central Basin				
Information Source	Predicted Ingress Volume (Mℓ/d) with no ingress control		Predicted Ingress Volume (Mℓ/d) with improved ingress control	
	Average	Range	Average	Range
WUC (2009)	59	47 - 102	49	37 - 92
This study	46	30 - 90	36	24 - 74
TCTA (2011) planned pumping rate	57	34 - 84	47	24 - 74
Eastern Basin				
Information Source	Predicted Ingress Volume (Mℓ/d) with no ingress control		Predicted Ingress Volume (Mℓ/d) with improved ingress control	
	Average	Range	Average	Range
WUC (2009)	82	77 - 108	61	56 - 87
This study	80	70 - 100	59	49 - 79
TCTA (2011) planned pumping rate	82	38 - 110	61	17 - 89

10.3 Water Quality

The main sources of AMD being exposed pyrite-bearing reef in the mine void and surface tailings dumps, it is conceivable that the water quality of the mine void should for various reasons improve with time considering that:

- The AMD that formed during the initial filling of the void should become increasingly more diluted due to flushing by (mixing with) uncontaminated water ingress sourced from the surface and from deep fractures;
- The quality of surface water runoff down the void walls above the required ECL should gradually be less contaminated (depletion of pyrite and reduction in new AMD formation), provided runoff from tailings dams is contained (to avoid mixing);
- Progressive oxygen deficiency in the deeper levels should retard the oxidation of acid-producing minerals (reduction in new AMD formation);
- Sulphate-reducing and other bacteria may become active at deeper levels as long as nutrients are available (natural bio-mediated sulphate processing); and
- Dolomite-equilibrated water will tend to reduce acidity of the AMD with time (mixing).

Due to the expected non-linearity of these quality-enhancing trends, the timing and extent of such improvements in water quality are extremely difficult to quantify with reasonable confidence. Rough projections suggest that under ideal conditions, several decades may be required. A more aggressive approach to pollution control is required.

In **Table 10.4**, the current estimates of the chemistry of the AMD in the three basins are compared with that listed by the TCTA (2011). As a general observation, it appears that the data sources consulted in this study report lower salt concentrations than the TCTA (2011). However, some variability in the water quality during the initial stages of pumping should be expected. This situation will stabilise when the systems approach dynamic equilibrium.

Table 10.4: Summary comparison of chemical data

		TCTA Report			This Report		
Water Quality Parameter	Units	Basin			Basin		
		Western (95th percentile)	Central (95th percentile)	Eastern (flooded condition)	Western (95th percentile)	Central (95th percentile)	Eastern (95th percentile)
pH*	-	3.4-4.0[#]	2.3	5[#]	3	3.2	7.1
TDS	mg/ℓ	7 174	7 700	5 500	5 400^	3 700^	4 300^
Conductivity	mS/m	548	730	450	426	354	367
Calcium (Ca)	mg/ℓ	461	580	550	823	483	421
Magnesium (Mg)	mg/ℓ	345	380	230	-	161	165
Sodium (Na)	mg/ℓ	139	150	325	243	185	264
Sulphate (SO_4)	mg/ℓ	4 556	5 200	3 275	3 410	2 464	2 581
Chloride (Cl)	mg/ℓ	65	260	260	-	69	253
Acidity/Alkalinity	mg/ℓ	2 560**	2 425**	750**	1 255[+]	125[##]	541[##]

Water Quality Parameter	Units	TCTA Report			This Report		
		Basin			Basin		
		Western	Central	Eastern	Western	Central	Eastern
		(95th percentile)	(95th percentile)	(flooded condition)	(95th percentile)	(95th percentile)	(95th percentile)
Iron (Fe)	mg/ℓ	933	1 000	370	799	177	206
Aluminium (Al)	mg/ℓ	54	50	1	-	44	2
Manganese (Mn)	mg/ℓ	312	60	10	114	20	6
Uranium (U)	mg/ℓ	0.2	-	-	0.1	0.2	0.5
*5th percentile # Assumed 5th percentiles **Acidity - Calculated $CaCO_3$ +Acidity mg/ℓ ##Alkalinity mg/ℓ $CaCO_3$ ^Estimated and numbers rounded up All units as quoted in source documents							

Table 10.5 shows the 95th percentile water chemistry from underground samples only (or direct decant sites in the case of the Western Basin), which provide a reasonable approximation of the likely water qualities during abstraction.

Table 10.5: Summary 95th percentiles underground/decant mine water chemistry

Parameter	Unit	Basin 95th Percentile)		
		Western	Central	Eastern
pH#	@ 25˚C	3.5	2.4	5.9
TDS^	mg/ℓ	5 434	4 592	3 358
Conductivity	mS/m @ 25˚C	442	465	363
Ca	mg/ℓ	703	563	421
Mg	mg/ℓ	-	258	166
Na	mg/ℓ	227	171	264
SO_4	mg/ℓ	3 623	3 062	2 289
Cl	mg/ℓ	-	146	254
Acidity/Alkalinity	mg/ℓ	1 520	-	560
Fe	mg/ℓ	954	108	227
Al	mg/ℓ	-	193	2.4
Mn	mg/ℓ	89	50	5.9
^Estimated # 5th percentile				

Principal component analysis of the water quality under discussion (detail not shown here) suggests a rather simple mixing relationship that informs the hydrochemical composition. The bulk proportion of the variance can be explained by three components, which have pH, the salt load (TDS as represented by EC) and Al as main variables. The Al-content is inversely proportional to the pH. These relationships are illustrated in **Figure 10.1**.

Following the general terms explained in **Section 5**, the following observations are relevant:

- Data cluster at K is regarded as the best average estimate of original Witwatersrand AMD. These samples have pH values of between 2 and 4, and TDS values of ca. 3 850±1 000 mg/ℓ.
- Most of the Western Basin AMD samples plot in a narrow band at an EC of ca. 350 mS/m (which represents a TDS of about 3 850mg/ℓ), and recorded pH values of between 2 and 7, depending on the degree of neutralisation (red arrow), probably by interaction with dolomitic water.
- The Central Basin data is scattered over a wide field, reflecting the diversity of samples in the database, from extremely contaminated surface sample (EC ~1 050 mS/m) to water within the potable range (EC <170 mS/m; SANS 241-1, 2011). A large number of samples plot at an EC of ~100 to 200 mS/m and pH between 2 and 6. The latter samples originate largely from the DRD Circular and CM 3 Vent Shafts, and represent the dilution effect of surface ingress (blue arrow) on the AMD in the mine void.
- The Eastern Basin samples cluster at an EC of about 300 mS/m (TDS ~3 300) and pH between 5 and 8. These samples follow a trend (black arrow) which summarises the recorded improvement of the water quality during pumping. This improvement is probably the combined result of dilution and neutralisation by dolomite-equilibrated water.
- The water described by Holland and Witthüser (2009) are plotted for reference. Of interest is the water cluster that they referred to as influenced by anthropogenic sources (H&W Con in **Figure 10.1**) which overlap with water from the DRD No. 6 Shaft. The latter also show high alkalinity and nitrate values, and some form of human waste interaction is suspected.
- The salt distribution in the AMD shows relatively little variation in composition. The weight ratios of SO_4:Ca:Mg:Na:Fe:Al = 65:15:5:5:1:0.5 (ranges: 60-75:10-25:4-7:4-10:0.1-6:0-3), on average, determined for Central Basin data, seem to hold well for the other basins as well.

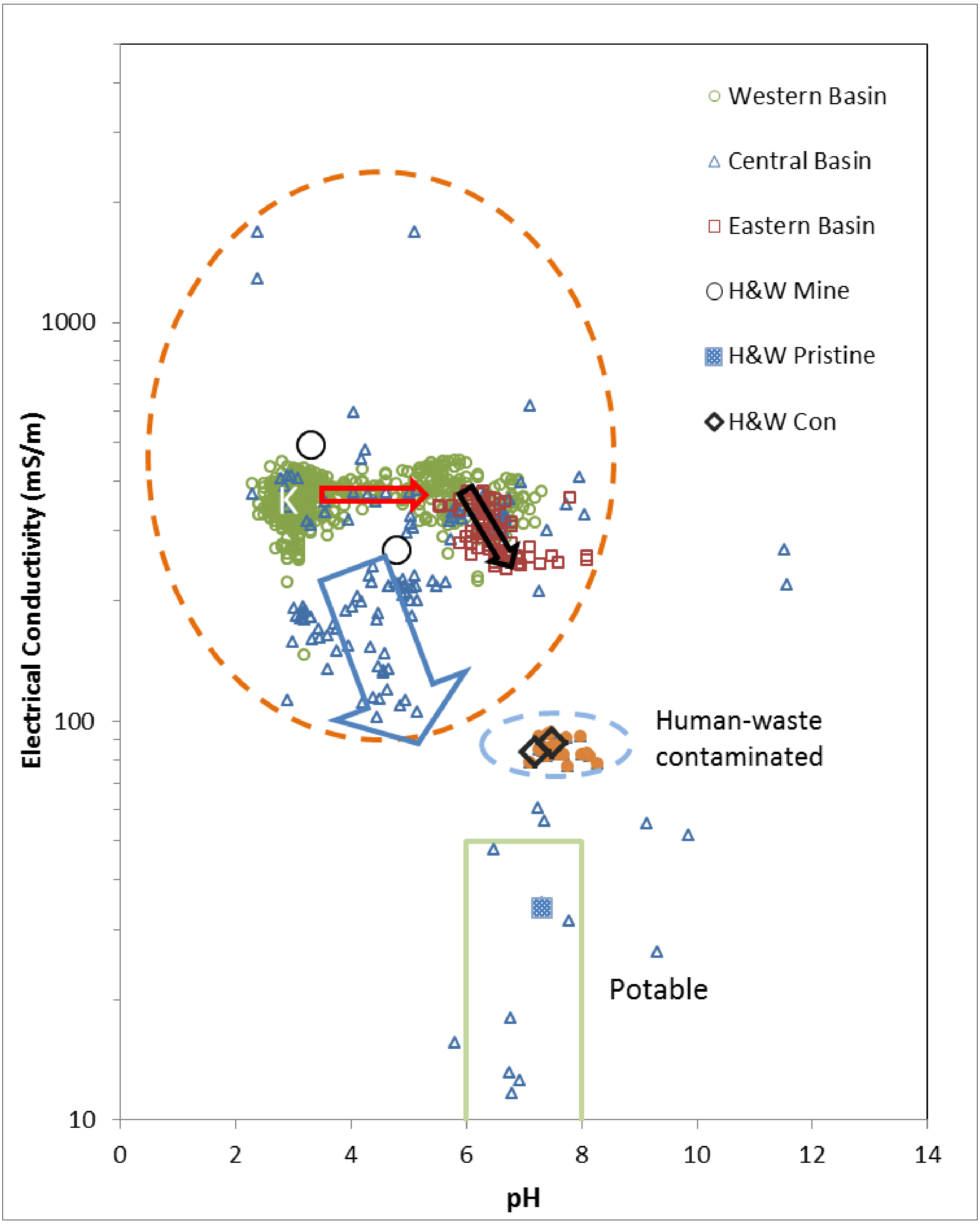


Figure 10.1: Simplified chemical relationships (H&W = Holland and Witthüser, 2009)

11 RECOMMENDATIONS

The STI (TCTA, 2011) is generally considered to be appropriate for addressing the immediate risks. Most of the recommendations addressed below are therefore pertinent only to the LTS. Only in the case of the Eastern Basin is there potentially sufficient time until the ECL is reached for the STI to consider these longer term recommendations.

11.1 Options Analysis for this Study

The following recommendations are for further investigation in the options analysis component of this Feasibility Study. It is understood that some of these recommendations may result in options being identified that are outside of the scope of the current study to define at the necessary confidence levels.

11.1.1 Abstraction sites

It is highly recommended that, for the Central and Eastern Basins alternative shafts be identified that may be suitable to use as pumping or monitoring sites and should therefore be secured for potential future use. Due to the constantly changing condition and status of shafts, in particular filling and capping, a comprehensive field investigation of potential sites would need to be undertaken as part of such a study.

In the Eastern Basin, consideration should be given to pumping from shafts in the south-eastern portion of the basin (Marievale) and Sub Nigel to reduce the pumping head.

a) Multiple abstraction sites

The current plan is to pump water from the Central Basin via a single shaft at ERPM. This has certain disadvantages, perhaps the most important of which are the deep level at which the shaft connects to the mine void and the fact that the pumps are situated at one end of the 50 km strike length of the void. This will mean that the pumps will perpetually draw water from deep in the void and moreover, ingress water entering in the west will have to flow the entire length of the void before being pumped to surface. These factors will inhibit shallow circulation in the void and the expected improvement in water quality that this could bring about.

As an alternative to pumping void water from a single, deep shaft, it has been suggested that a number of smaller distributed pumps could be installed. This will reduce the risk from failure of a pump shaft due to collapse of the shaft itself or underground haulages. In addition, pumping from shallower levels is likely to result in a more rapid improvement in the pumped water quality. Ideally, shafts that are better connected to the mine void at multiple and preferably shallow levels are recommended. In the Central Basin, there are numerous incline shafts across the length of the basin that could be investigated for their suitability as pump locations. However, many of these have been filled.

Access and infrastructural constraints may necessitate the consideration of large-diameter boreholes drilled into the mine void for pump installation. It should also be noted that serious obstructions have been encountered in some shafts during water monitoring, resulting in lost time and equipment; this could be considered as an additional argument in favour of dedicated boreholes for pump installation. The critical considerations for identifying potential abstraction borehole sites are:

- Determining optimum spacing for pump stations across the basin based on pump and treatment capacities;
- Sourcing and analysing accurate mine plans to identify suitable stopes and haulages with good interconnectivity at a shallow level; and
- Identifying suitable sites for surface infrastructure.

The most suitable locations would be those that intersect positions in incline shafts where large voids were made to accommodate pumping and other underground infrastructure. Most of the incline shafts are sealed near surface, but at envisaged pumping depths, these shafts will almost certainly still be open. The boreholes could be either inclined or vertical, making for easier positioning in very developed areas. An example of an incline shaft that could be utilised initially to test the methodology is the Cason Incline Shaft in the Central Basin (see **section 7.6.2**). Water pumped during the testing could be treated and disposed of via the SWV treatment facility. **Table 11.1** indicates the approximate cost for a 400 m deep borehole completed with 300 mm stainless steel screens but excluding mobilization costs, in the Witwatersrand lithologies.

Table 11.1: Cost estimate for a 400 m deep, 300 mm diameter abstraction borehole

Item	Unit	Quantity	Rate	Sub Total
Establishment	sum	1	R20 000.00	R20 000.00
Set-up	sum	1	R8 500.00	R8 500.00
Security	sum	1	R12 000.00	R12 000.00
Drilling 17" (444 mm) weathered formations	m	24	R2 750.00	R66 000.00
Plain steel casing 16" 406 mm (6 mm)	m	24	R1 825.00	R43 800.00
Drilling 15" (381 mm) 0 - 50 m	m	26	R2 600.00	R67 600.00
Drilling 15" (381 mm) 50 - 100 m	m	50	R2 860.00	R143 000.00
Drilling 15" (381 mm) 100 - 150 m	m	50	R3 146.00	R157 300.00
Drilling 15" (381 mm) 150 - 200 m	m	50	R3 460.60	R173 030.00
Drilling 15" (381 mm) 200 - 250 m	m	50	R3 806.66	R190 333.00
Drilling 15" (381 mm) 250 - 300 m	m	50	R4 377.66	R218 882.95
Drilling 15" (381 mm) 300 - 350 m	m	50	R5 253.19	R262 659.54
Drilling 15" (381 mm) 350 - 400 m	m	50	R6 303.83	R315 191.45
Drilling fluids	m	400	R135.00	R54 000.00
Water cartage	day	16	R750.00	R12 000.00
Sub Total				**R1 744 296.94**
Vat (14%)				**R244 201.57**
TOTAL				**R1 988 498.51**

The boreholes should intersect the void at a depth just below the bottom of the depth range envisaged for the TOL. The main disadvantage of this scheme is that the water level in the void will be variable only over a very small range, unless the holes penetrate the void at substantial depth (below the TOL), which will offset the advantages of tapping the void at a shallow level. The boreholes should be designed to accommodate a nominal 8" (203 mm) or 10" (254 mm) pump with a total dynamic head of 300 m and capable of pumping at 100 m^3/hr (~28 ℓ/s) and should therefore be completed at a nominal inside diameter of 12" (304 mm) or 14" (355 mm) (**Figure 11.1**). The pump would be placed within the casing for protection, but it is assumed that the Witwatersrand rocks at this depth will be competent enough. The remainder of the borehole would be left open into the void.

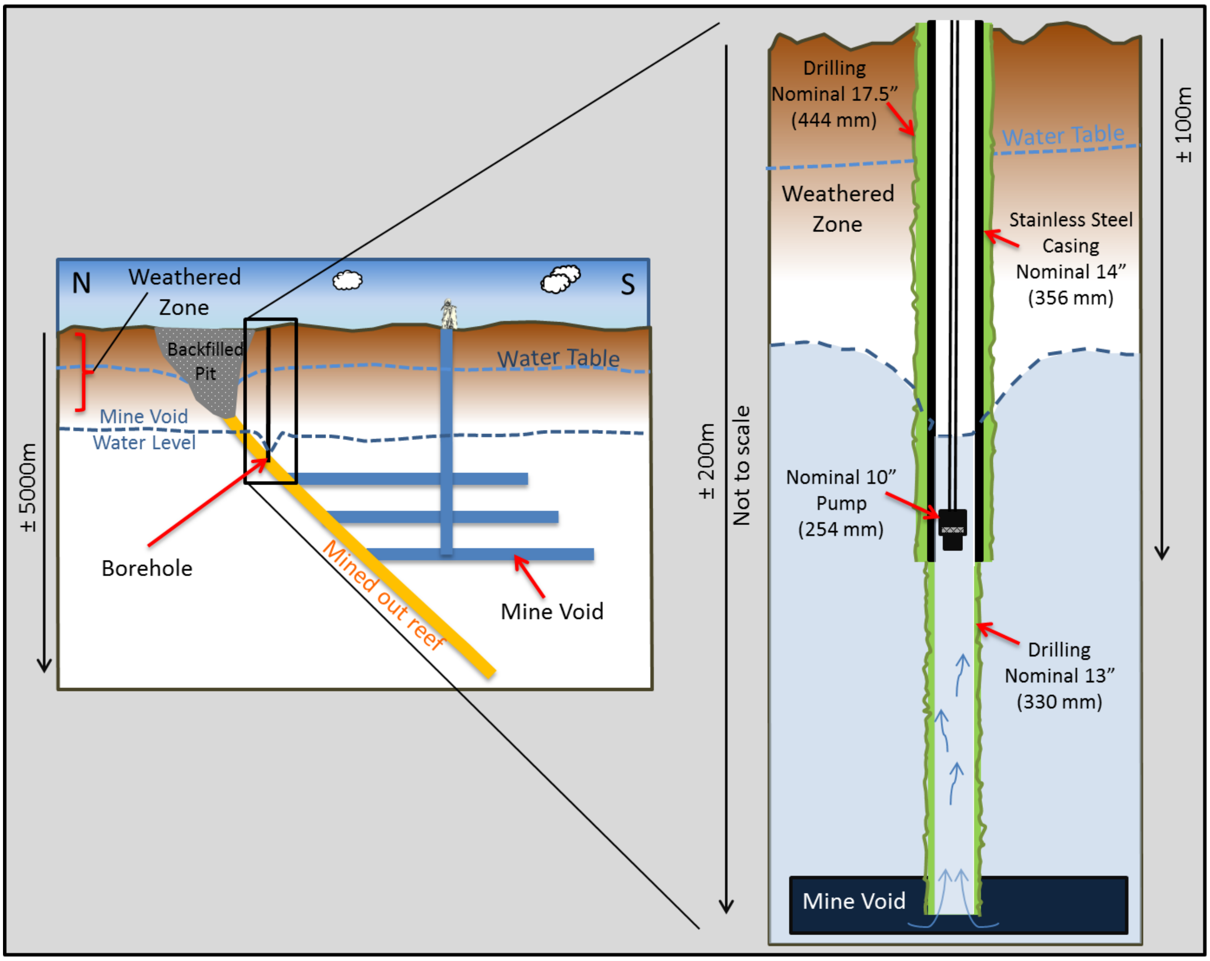


Figure 11.1: Schematic illustration of a proposed abstraction borehole drilled into the mine void

In any of the multiple site scenarios described above, pipelines may have to be installed to convey water to central treatment plants in a similar manner to that employed by the companies that re-treat slimes dumps. The feasibility of installing small modular treatment plants should therefore also be considered to offset all of the costs associated with a pipeline network.

b) Pump capacity

As discussed in several sections of this report, the water levels in the Central and Eastern Basins should be initially maintained at the lowest safe ECL possible and then raised slowly, with careful monitoring (EC and water levels) throughout to optimise the ECL and TOL. Dewatering of the isolated and saturated dolomite aquifer in the Western Basin may require long lag times and/or additional pump capacity to reach the TOL. These factors will need to be considered during pump selection.

c) Alternative options to pumping

Controlled decant by means of a tunnel is a potentially viable option for the Central and Western Basins. This could be achieved by connecting the mine void to a point on surface at an elevation equal to or below the ECL/SECL.

The primary advantage of a controlled decant option is to remove or limit the need for pumping from surface. This would have a significant impact on the long-term running and maintenance costs and be essentially self-sustaining.

The following aspects should be considered in the options analysis of the tunnel concept:

- The TOL for each tunnel option would need to be determined;
- Accurate Digital Elevation Models (DEM) would need to be sourced and investigated to establish the best surface outlet point for the tunnel;
- 1 in 50 and 1 in 100 year flood lines would need to be considered since the lowest elevations on surface will coincide with drainage lines;
- Sourcing and analysing accurate mine plans in order to establish the shortest distance between the decant point and the mine void;
- Borehole drilling along the planned tunnel site to determine the geotechnical characteristics of the rock; and
- Evaluation of the potential surface decant sites for the placement of the water treatment plant.

11.1.2 Sludge disposal

As discussed in **Section 5.3**, it is not considered prudent to dispose of the HDS into the mine void if not isolated sufficiently from the main void, since under the acid environment, the metal oxides will dissolve into the void water over time. This will result in continual recycling of the more serious pollutants and the anticipated improvement in the quality of water being pumped from underground could be seriously delayed.

In addition to the chemical factors, there are also physical and economic arguments against the disposal of sludge into the mine void, including the sterilisation of areas that may become economically viable for renewed mining activities in the future. However, the cost associated with residue management and disposal, may necessitate further investigations to assess the feasibility of underground disposal.

Ideally, the sludge should be converted into a saleable form. If the iron could be separated from the gypsum, it could possibly be used as a pigment in paint or sold to scrap metal recyclers. Every effort should be made to achieve this goal. Co-disposal with tailings is considered to be a sensible option in the interim.

11.1.3 Central Basin SECL

A major point of concern regarding the SECL (and to a lesser extent the ECL) in the Central Basin is the fact that proposed abstraction will take place only from the far eastern end of the void. Recharge, on the other hand, occurs across the full 55 km length of the basin. Should flow through the void be in any way impeded, the water level in the western and even the central portion of the Basin could rise significantly above the envisaged TOL. This could have dire consequences for the underground museum at Gold Reef City because of the limited freeboard between this position and the abstraction point on ERPM. Although the TOL will be finalised outside of this component of the Feasibility Study, it is suggested that the pumps be installed at least 50 m below the SECL, and that the water level in the void at various points across the basin be carefully monitored once pumping starts in order to obtain data on the lateral flow rate. If the flow rate is slow, the TOL may have to be adjusted to keep the water level in the void below the mine museum level.

If the water were allowed to decant at ERPM, the water in the void would rise to at least 1 620 m amsl, leaving only 1 Level (approximately 1 671 m amsl) safely above the water level and 2 Level (approximately 1 624 m amsl) at significant risk. If the TOL was set based on the proposed 1 520 m amsl ECL (which would likely be a similar elevation should the tunnel option be applied), then the 5 Level museum facility would also be flooded (**Figure 7.11**). In this scenario, the static water level would be located just below 4 Level (approximately 1 526 m amsl), and either redevelopment of the museum facility at a shallower depth (e.g. 2 Level), or isolation of 5 Level from the flooded void via underground plugs would be necessary.

11.2 General Recommendations

11.2.1 Water monitoring

The water monitoring programme that is being developed by the Hydrological Monitoring Committee of the DWA is strongly endorsed. It is recommended that the monitoring strategy (levels and qualities) should include both the mine void and the surrounding natural groundwater resources. On-going monitoring of water levels across all basins is essential both in the period preceding the installation of the pumps by TCTA and especially thereafter.

The Management Authority (MA) of the Cradle of Humankind World Heritage Site has commissioned a project to monitor the water resources in the wider area downstream of the

Western Basin. Reports on the status of the water resource environment (Hobbs, 2012; 2013) have indicated that there was an 18 month period of severe impact triggered in January 2010 with the commencement of uncontrolled raw mine water discharge in significant quantities from the Western Basin. The impact was manifested on both surface water and groundwater resources in the Bloubank Spruit system and the downstream (north-eastern) portion of the Zwartkrans Compartment. A return to pre-2010 discharge conditions in mid-2012 with the commissioning of the immediate mine water control and management interventions, is evidenced in the improved quality of surface water in the Bloubank Spruit system by August 2012. An improvement in the groundwater quality will take significantly longer to, although an indication that this has commenced is suggested by the most recent (February 2013) monitoring results (Hobbs, 2013).

Water quality data for the Central Basin is limited when considering mine void/stope data. Drilling boreholes into the mine void or using existing boreholes (drilled by Central Rand Gold) and sampling for water quality analysis is highly recommended to better understand the potential water quality expected for treatment.

Identifying more monitoring stations for the Eastern Basin is critical to determine the level of interconnectivity between the mines. Moreover, it is essential that regular monitoring of the raw water be carried out in all basins in order to detect changes in water quality with time.

11.2.2 Isolated mine voids

Certain reef horizons across the three basins were extensively mined and the resulting voids are fairly well connected to each other. However, there are reefs where limited mining took place which are isolated from the main voids and will fill as independent sub-basins.

Many of these small voids may not actually decant. In order for decant to occur, it is necessary that the natural water table somewhere in the void ingress area should lie at a higher elevation than a shaft collar or other opening to the void. On horizontal ground, therefore, the water level in the shafts accessing the void will rise to the water table and no further. In cases where ingress volumes are small, shaft water may decant into the ground water and never appear on surface. Therefore, each of these isolated voids will behave differently and once identified, each will have to be considered on its merits.

The number of such isolated sub-basins is unknown and it is recommended that these be identified by a detailed examination of mine plans held by the DMR.

11.2.3 ECL evaluation and review

In the Western Basin, it is strongly recommended that the water level is held at the 1 600 m amsl (or respective TOL) during pumping to allow for sufficient lag time while the isolated and saturated shallow dolomite aquifer dewaters. This will permit the appropriate evaluation of the proposed ECL through water quality monitoring within the dolomite outlier and in the Lodge Spring area of the Krugersdorp Game Reserve. It is critical, however, that appropriate water quality monitoring stations are in place, otherwise the water should be held at the original TCTA recommended ECL of 1 550 m amsl until such time as the monitoring stations are installed and operating.

A program of drilling across the Central Basin is recommended to define the depths of the shallow aquifer. This will enable an optimum elevation for the Central Basin ECL to be determined.

Collar elevations for key shafts have been an issue, with some shafts reporting elevations with differences exceeding 10 m depending on the source. It is understood that the DMR is in the process of completing a verification exercise in this regard. This is strongly supported and should be completed across the basins.

11.2.4 Ingress control improvements

As identified in this study, the ingress of surface water via various sources has a fairly significant effect on the expected pumping rates for each of the basins. At present no detailed assessment as to the practicality and cost implication can be made for the control of ingress, as this currently falls outside the scope of work. It is therefore recommended that follow-up studies be undertaken to better define the ingress points and sources, as well as the extent, practicality and estimated cost to implement ingress reduction.

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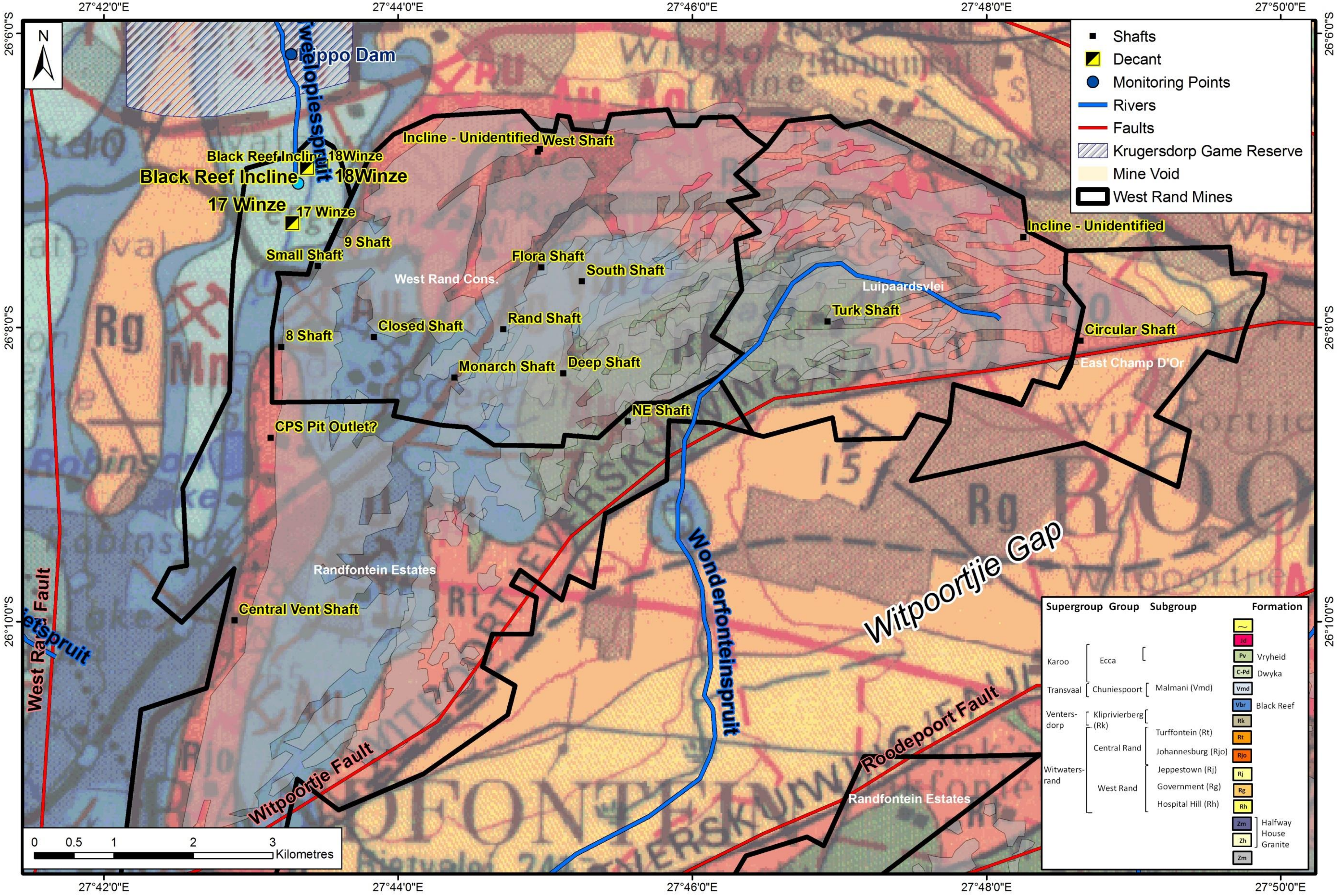
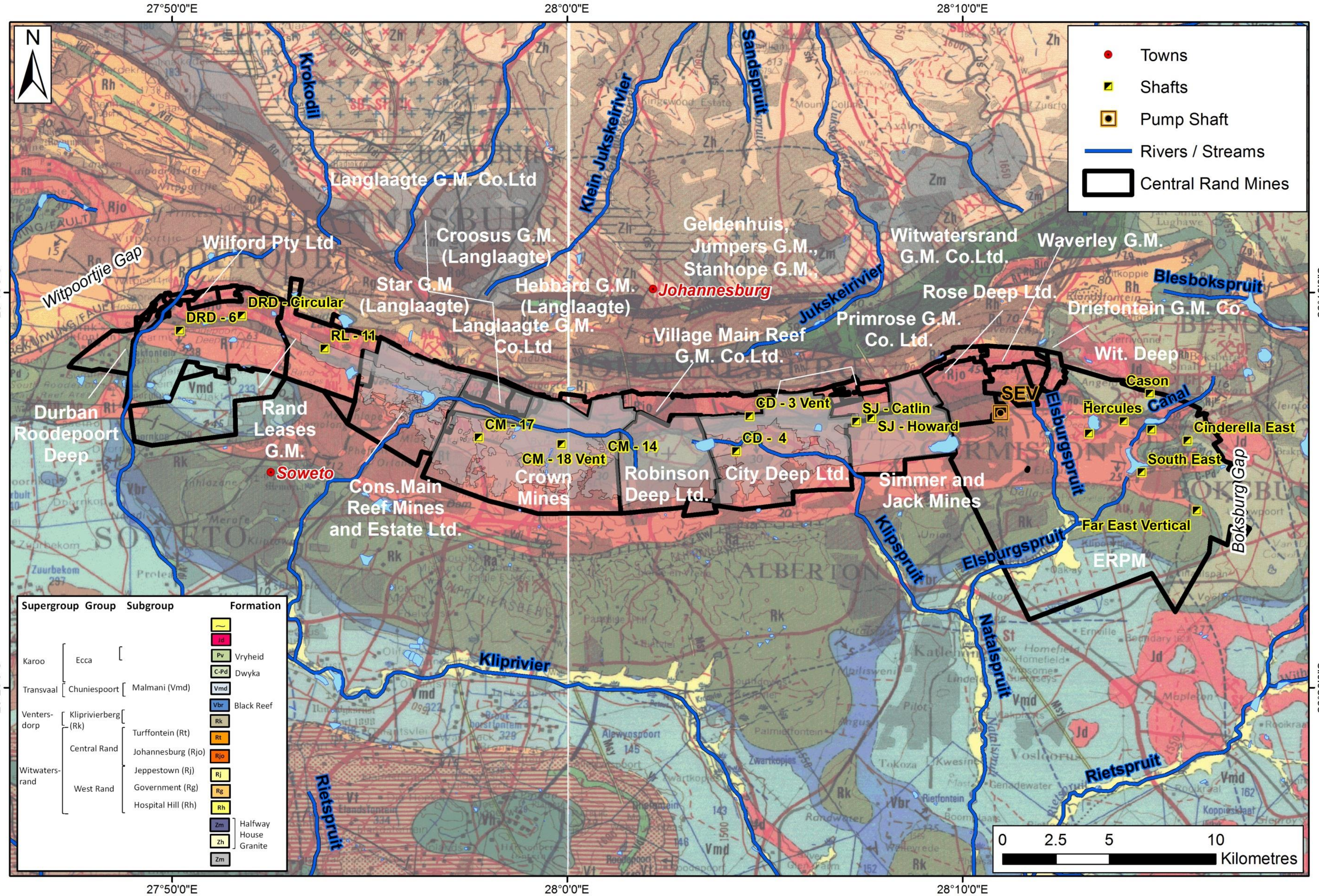
Appendix A
Summary Plans

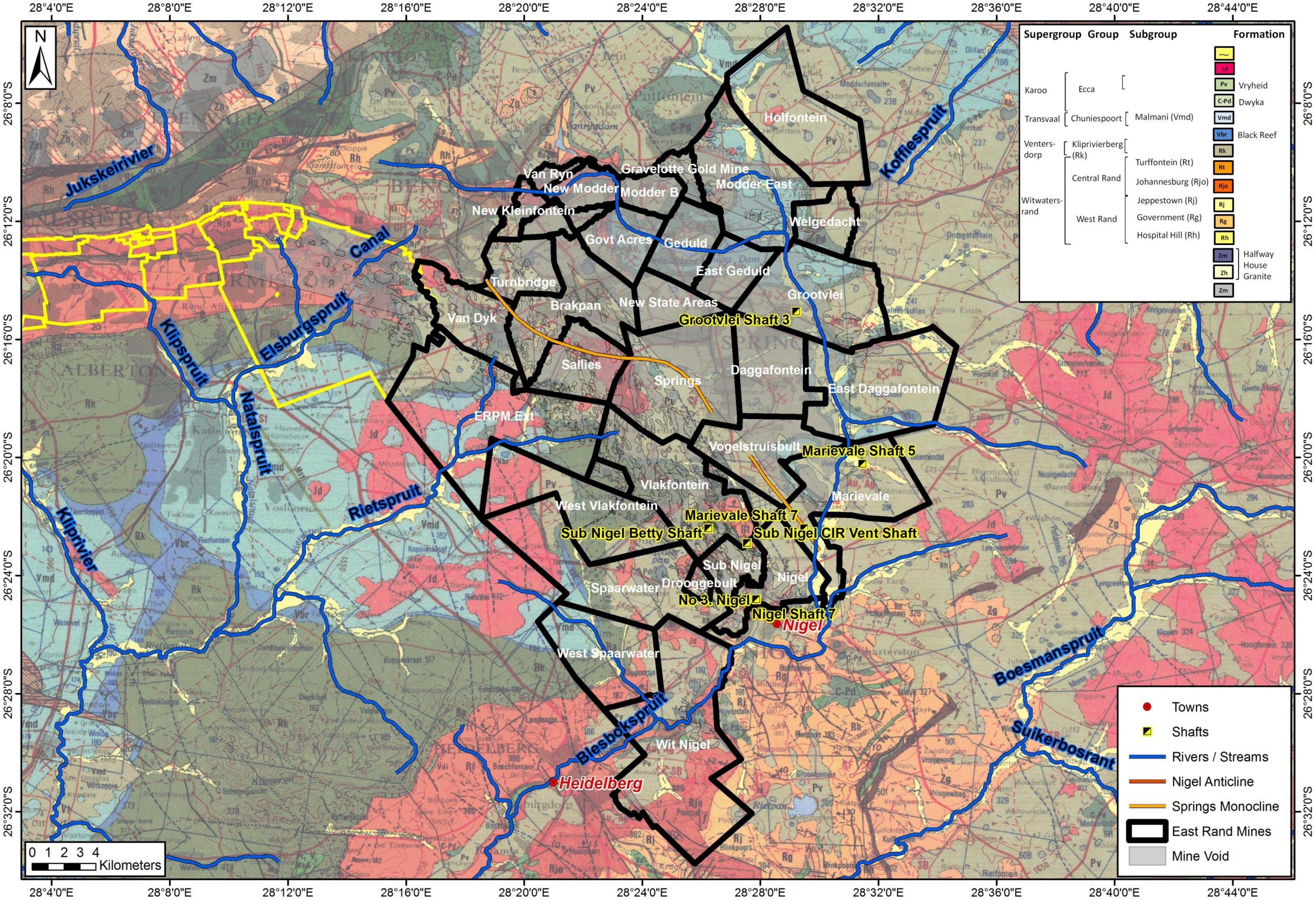
WESTERN BASIN



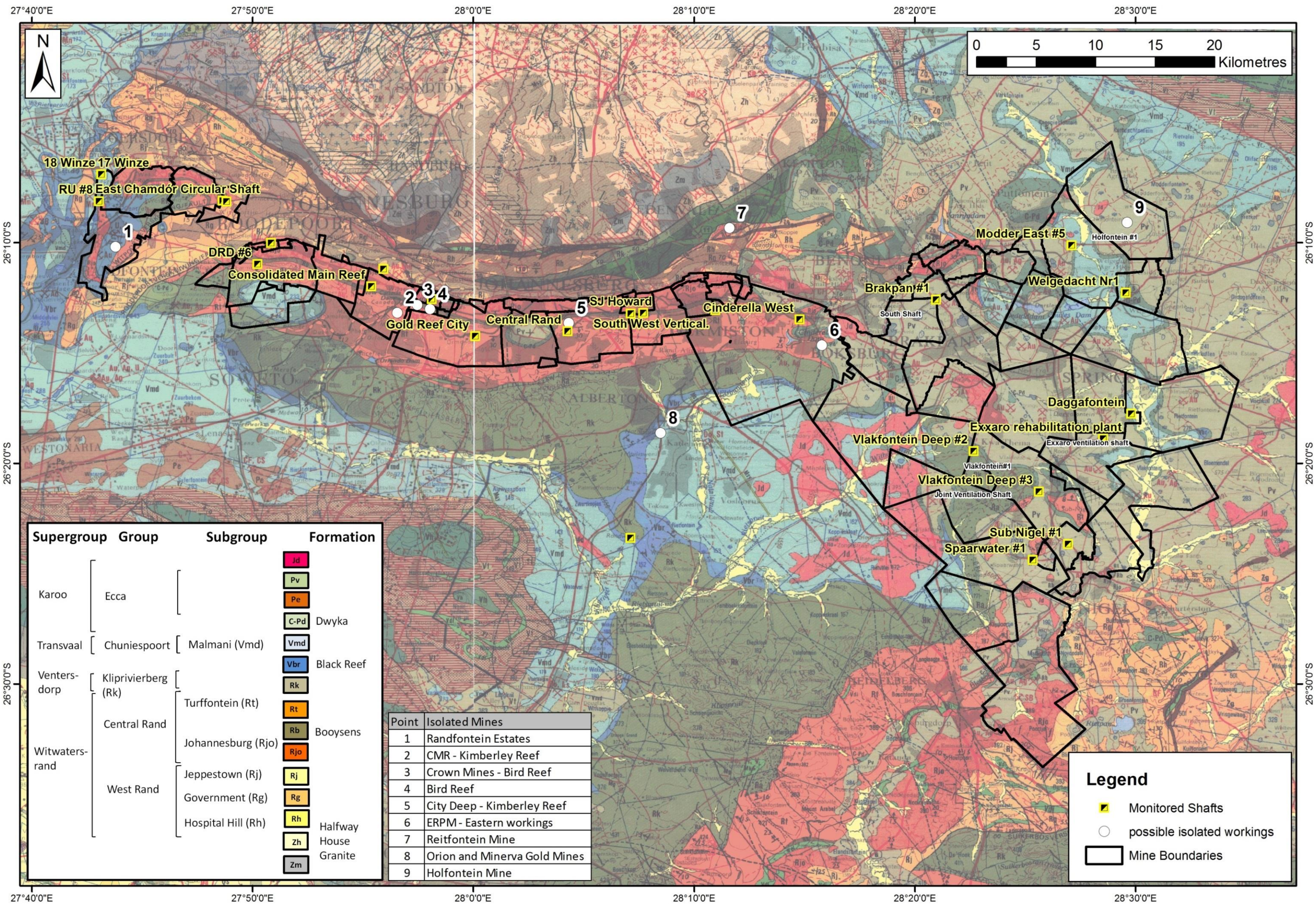
CENTRAL BASIN



EASTERN BASIN



Appendix B
Isolated Mines



Point	Isolated Mines
1	Randfontein Estates
2	CMR - Kimberley Reef
3	Crown Mines - Bird Reef
4	Bird Reef
5	City Deep - Kimberley Reef
6	ERPM - Eastern workings
7	Reitfontein Mine
8	Orion and Minerva Gold Mines
9	Holfontein Mine

Appendix C
Suggested Ingress Reduction Measures for Each Basin

Suggested Ingress Reduction Measures for Each Basin

East Rand Basin					
No.	**Ingress area**	**Proposed Actions**	**Aspects to consider**	**Costs for preferred option**	**Reference**
1	West Pit	Build canal AND unblock culvert	Change current ecology of stream		Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
2	Cowles	Mine sediments and divert flow around the dam	Change dam ecology; Destroy dam ecology (Sappi bird hide developed at Cowles dam)	R40 953 345	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
3	South Blesbok	Unblock or enlarge culverts AND divert flow over certain portions – significant volume to be saved	Change ecology	R343 750	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
4	Leeupan	Reduce the grey water entering the pan by collecting the water and discharging the water to the sewage reticulation network. Line pan, Ekurhuleni is in an advanced stage of developing the pan as nature reserve, flow diversion will nullify purpose of nature reserve	Water continues to ingress at a high rate; Change ecology	R50 344 989	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
5	Central Blesbok	Unblock and enlarge culverts AND Divert flow over certain portions – significant volume to be saved	Change ecology	R5 833 985	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
6	North Blesbok (northern area)	Unblock and enlarge culverts AND divert flow over certain portions – significant volume to be saved		R6 027 344	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
7	North Blesbok (southern area)	Unblock and enlarge culverts		R343 750	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
8	Van Rhyn (ponding)	Repair channel which will remove the dam - Should reduce ponding significantly, getting rid of the unnatural dam		R34 205 241	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
9	Van Rhyn (direct runoff)	Close cracks and stabilize openings		R6 908 400	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
10	Largo	Close openings – foam	Foam might shrink?	R49 598 350	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
11	Gravelotte (opencast mine, open shaft)	Shaft closing costs low enough, costs to close opencast mine too high to be feasible. Construct upstream bunds		R1 832 700	Regional mine closure strategies for the East Rand Basin, Table 1, p. 35. IMC Report Section 12.5.
12	New Kleinfontein	Repair channel		R10 297 172	IMC Report Section 12.5.

Central Basin					
No.	**Ingress area**	**Proposed Actions**	**Aspects to consider**	**Costs for preferred option**	**Reference**
1	Johannesburg and Ekurhuleni	Embark on a programme together with the relevant Metro Councils to alleviate risk.			IMC Report Appendix A.
2	Elsburgspruit	Discharge point should be downstream of potential ingress area, or discharge should be via an impervious canal.			IMC Report Appendix A.
3	No specific location given	Proper waste management will reduce the risks			
4	Boksburg Canal	Assess ingress and feasibility of canal construction Canal construction			IMC Report, Section 12.5
5	Surface stream – City Deep to Consolidated Mine	Assess ingress and feasibility of canal construction Canal construction			IMC Report, Section 12.5

Western Basin					
No.	**Ingress area**	**Proposed Actions**	**Aspects to consider**	**Costs for preferred option**	**Reference**
1	No specific location given	Minimisation of ingress via open pits by backfilling with tailings (from reprocessing plants) and capping and shaping to prevent future ingress.			Regional Closure Strategy for West Rand Goldfields, p 90
2	No specific location given	Prevention of the flow of runoff from Dump 20 into the Millsite Pit. Investigation of and, if necessary, addressing of possible ingress along the Witpoortjie Fault after lowering of the void water level to the ECL.			Regional Closure Strategy for West Rand Goldfields, p 90
3	No specific location given	Identified diversion of stormwater into abandoned surface workings in Krugersdorp. Prevention of the flow of stormwater into open pits. Audit of possible ingress via urban stormwater system. Upgrading of stormwater management to prevent ponding, encourage runoff and ensure that stormwater is discharged to streams away from areas where ingress to the mine void is possible.			Regional Closure Strategy for West Rand Goldfields, p 90
4	No specific location given	Audit of possible reticulation and sewer losses.			Regional Closure Strategy for West Rand Goldfields, p 90
5	No specific location given	Investigation of potential ingress from existing residue deposits. Removal of residues and capping/shaping remaining deposits.			Regional Closure Strategy for West Rand Goldfields, p 90

Appendix D
Report back on a Visit to Gold Reef City's 14 Shaft

Report-back on a Visit to Gold Reef City's 14 Shaft
On 8th October 2012

Present: Mr Sidney Segal and other Gold Reef City Staff
Prof Terrance McCarthy, Wits University
Mr Andrew Tanner, Aurecon
Mr Dave Stewart, Shango Solutions.

Reason for the meeting:

(See **Figure 1** for General Mine Plan and **Figure 2** for locations mentioned in the text.)

On Thursday 4th October, 5 Level, the tourist level on No. 14 Shaft, Gold Reef City (GRC), flooded and tourist visits were stopped. The water level on the 5 Level Reef Drive at the Main Incline Shaft, to the west of No. 14 Shaft, was such that water flowed into the gum boots of GRC staff conducting site investigations, i.e. about 35 to 40 cm deep. Between then and Monday, 12th October, pumps were installed on 5 Level at the Incline Shaft. This resulted in the water level being lowered to about 2 m vertical below 5 Level.

An initial meeting was held on surface where the following was confirmed:

- The Main Reef mine void water level in No. 14 Shaft was 345 m below surface on 5 October (the day after the flooding commenced);
- The Kimberley mining area represents an isolated hydrological compartment with the only holing to No. 14 Shaft being on 5 Level;
- The flooding on 5 Level is thus not connected to the water rise in the Central Basin; and
- The decision on whether to re-establish the tourist section on 2 Level will be delayed till January 2013.

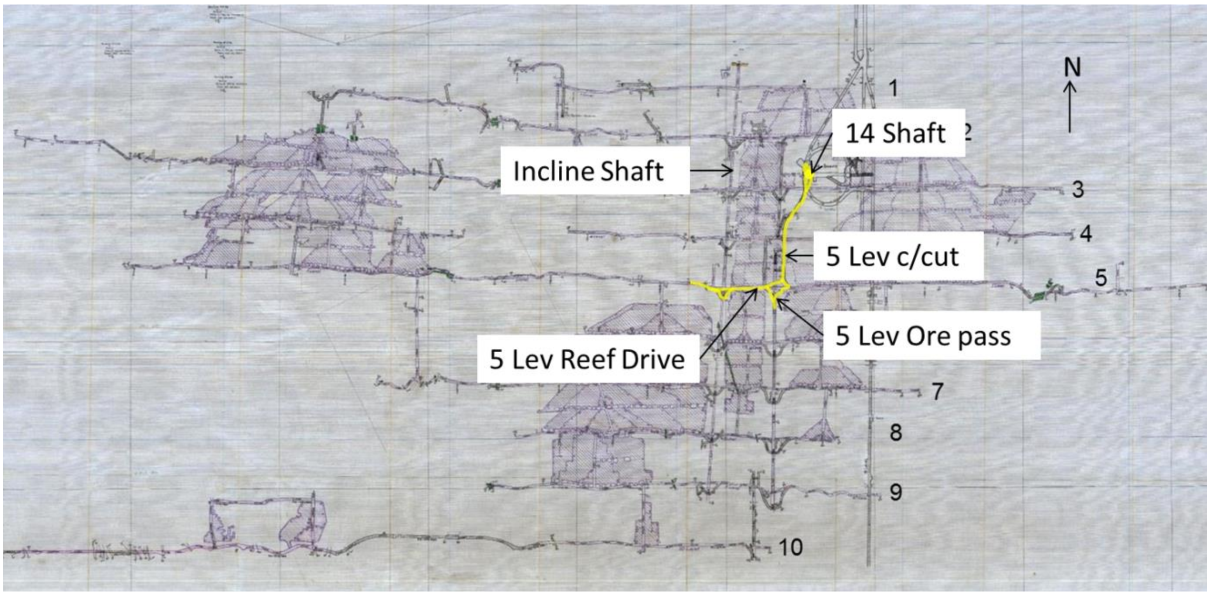


Figure 1: No. 14 Shaft, Gold Reef City, general Mine Plan.

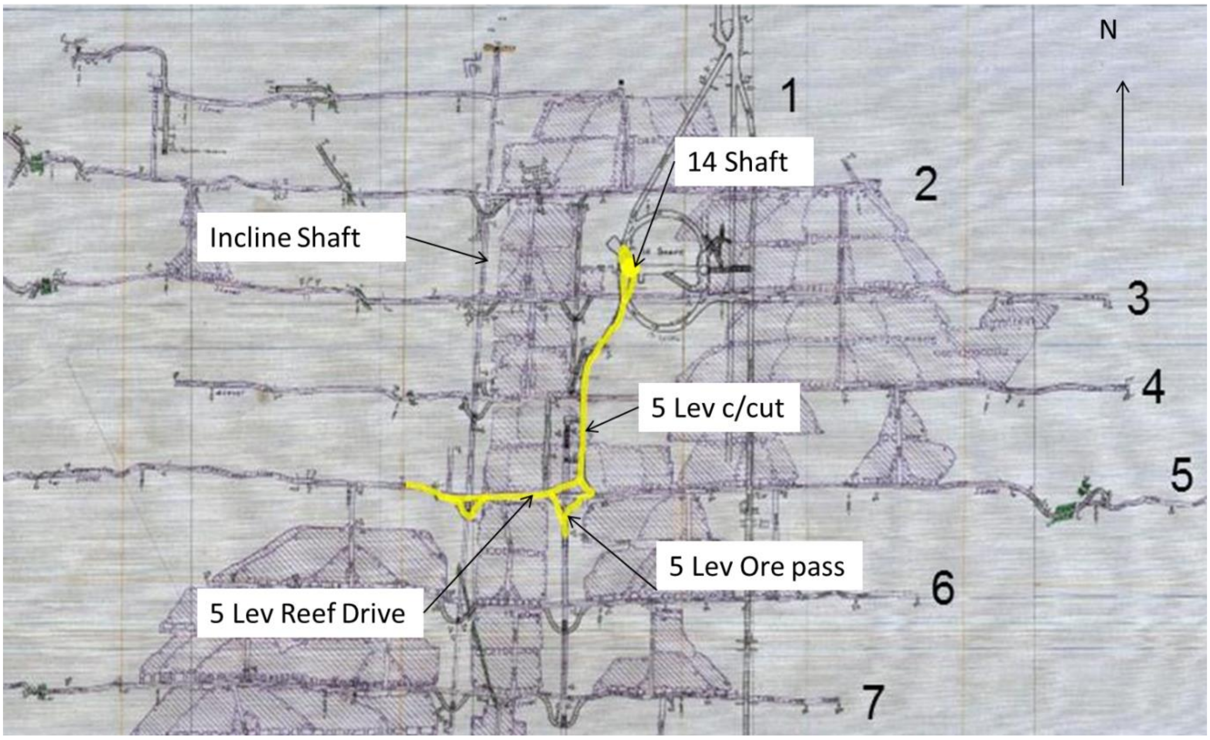


Figure 2: Detail of locations.

Underground Site Inspection:

The underground visit confirmed the following:

- The pump installed at the Incline Shaft was operating and the water was being pumped from about 2 m below 5 Level to mid-way along the main 5 Level cross cut;
- From the pipe's discharge point, the water was gravitating back to No. 14 Shaft along the cross cut; and
- A leak in the pipe, half way between the Main Decline and the 5 Level cross cut, showed that the leaked water was flowing back to the decline. The gradient of the reef drive is thus upward away from the decline.

Follow-up Discussions

Upon returning to surface, discussions over a plan resulted in the following recommendations:

- Suitable pipes should be installed from the pump at the Main Decline to No. 14 Shaft to allow water to be discharged down No. 14 Shaft;
- The ore pass at the south end of the 5 Level cross cut should be cleared of rock and this used as a sump for future pumping;
- Permanent piping and pumps to be installed either at the ore pass or in the stope to the east of the cross cut;
- Water on 3 level is pumped to surface for use by GRC's entertainment area. Excess water flows down the Incline Shaft;
- The dam on 3 Level to be investigated regarding storage of excess water which could be pumped to surface for use by GRC instead of municipal water;
- The volume of water flowing down the Incline Shaft from 3 Level to 5 Level to be determined. This water should be piped down the Incline and on to No. 14 Shaft for discharge down that shaft; and
- The Incline Shaft to be re-habilitated between surface and 5 Level (for interest only).

Subsequent to these discussions, a meeting was held where three representatives of Metgroup were present. These discussions centred on the work to be conducted underground. Some of the work had been planned before the flooding, the rest was detail of how the water was to be controlled.

Subsequent considerations

Discussions at the Shango Offices, following the visit, resulted in the following:

- Would it be feasible to create a siphon between the water in the stopes below 5 Level and No. 14 Shaft thus saving pumping costs?;

- The change in pH from 7 on 3 Level to 4.2 on 5 Level seems to be extreme over such a short distance. The following were considered:
  - The slope distance between the two levels is estimated to be about 175 m (100 m/sin(35º));
  - If the water is flowing at 0.5 m/second, it will be in contact with the rock between the two levels for less than 6 minutes;
  - The footwall of the decline is probably quartzite for most of the way;
  - The water has probably been flowing over this footwall for decades;
  - The temperature of the water is generally cool;
  - Why the change in pH unless water with a low pH is being added from elsewhere?;
  - If so, from where and at what pH is this added water?; and
  - This to be investigated.

Dave Stewart

8th October 2012

ADDITIONAL NOTE ON THE FLOODING INCIDENT AT GOLD REEF CITY

Measures implemented by Gold Reef City management, viz. interception of ingress down the incline and periodic pumping of water from the Kimberley Reef, have brought the water situation at the museum under control. According to Mr Darrell Phillips of Gold Reef City Museum, the water level in the Kimberley Reef void rises slowly necessitating regular pumping to prevent another flooding incident. The source of the ingress is not known at this stage.

Following discussions with Mr Peter Kelly, an inspector of mines from the DMR, it was decided to investigate the flooding incident at Gold Reef City in more detail. Mine plans showing workings on both the Kimberley Reef and the Main and associated reefs were obtained and thoroughly examined. It was found that the Kimberley Reef workings at No. 14 Shaft are connected to No. 15 Shaft via a tunnel on 10 Level (approx. 450 m below surface). This shaft is connected to a sub-vertical shaft (15A) on 21 Level (about 945 m below surface), which is connected to the Main Reef workings at depth. It thus appears that there should be complete connection between the Kimberley Reef void at No. 14 Shaft and the Main Reef void below, and the water level in the Kimberley reef void should equilibrate with that in the Main Reef.

However, on the 4th October 2012, when the flooding of 5 Level (216 m below surface) took place, the water level in the Main Reef void, as measured in No. 14 Shaft, was 346 m below surface, 130 m deeper than the water level in the Kimberley Reef void, indicating that the two voids are not connected. The reason for this is not known. Mr Kelly suggested that No. 15 Shaft has been filled with rubble and is totally blocked, accounting for the difference in water level. Alternatively, tunnels linking the voids may have collapsed, isolating the Kimberley Reef void from the Main Reef void.

The lack of connectivity of the voids at No. 14 Shaft has no material bearing on the filling of the Main Reef void, although it does indicate that there may be unexpected surprises as water level rises and pumping commences.

Dave Stewart and Terence McCarthy

5th June, 2013.

Appendix E

Expected water quality from the Witwatersrand mine voids

An assessment of the expected quality of water from the Witwatersrand mine voids

Summary

This brief review of the water quality data, as well as the way in which the data is interpreted, is an attempt to explain the apparent discrepancies that exist between the water quality estimates of TCTA and Shango Solutions, as reported in the report by the Department of Water Affairs (DWA), (2012). These deviations are probably largely the consequence of diverse interpretations of the relatively sparse data combined with temporal variation in the water qualities resulting from a variety of processes.

This note also presents possible models of the expected compositions of the mine void water to be abstracted from the three main Witwatersrand basins, i.e. the Western, Central and Eastern Basins. It would appear that two different scenarios are dealt with in the Western and Eastern Basins. The Western Basin, being in the decant stage, is in an advanced stage of rinsing of the void water through deep level flow. The data from the Eastern Basin suggests simple mixing, involving also treated water, within the mine void. The latter suggests large-scale recycling, supporting the notion that treated water should ideally be prevented from flowing back into the basin. The expected salt load in the water from the Central Basin is less certain due to an inadequate sample spread.

In view of these models, the salt loads for the three main basins, proposed by Shango Solutions in the DWA Report, are regarded as reasonable estimates of what can be expected during pumping.

Contents

Introduction

There appears to have been some queries on the water qualities quoted in the Department of Water Affairs (DWA), (2012) ("DWA Report"). From the information available, the main uncertainty seemingly relates to the differences in the expected salt loads of the AMD reported by Shango Solutions and TCTA. This note is an attempt to clarify the apparent confusion. In the process, the water qualities from the three main basins are discussed and modelled. The note is concluded with a summary of the possible water qualities that can be expected during the planned pumping exercise.

General Considerations

An ideal dataset for a given basin should contain samples regularly spaced in time and space and with a complete set of chemical parameters. Such an ideal dataset would allow the best possible interpretation of spatial and temporal variations in a given basin.

In contrast, the AMD datasets for the Western, Central and Eastern Basins, available to Shango Solutions at the time, were compiled from diverse sources with diverse sampling objectives and needs for comprehensiveness. The sample spreads (in space and time) vary between basins, and are inhomogeneous and incomplete. This fact, considered in conjunction with the discussion in Section 5.2 in the DWA Report, introduces considerable uncertainty as to what the chemistry of the void water really is. It follows that the numbers that were derived from the data inevitably are best estimates only, and cannot be construed as absolute or final.

In the selection and treatment of chemical data, a few general guidelines were constantly considered:

- Samples directly representing void water (underground, direct decant) would be better indicators of the relevant water;
- Due to the observed change (improvement) of water qualities with time, more recent data is probably more significant than older data;
- Datasets containing complete temporal records (for all samples and quoted chemical variables) are expected to yield less biased results than datasets with less populated records; and
- Datasets with complete chemical spreads are more useful than datasets with fewer chemical parameters.

It is understood that in the engineering profession, hard accurate numbers are preferred. However, in the current investigation these are not readily available and some assumptions are necessary. Moreover, with sparse data, the inferences that are finally made would out of necessity be somewhat subjective. However, if the arguments put forward here are found wanting by whomever, the estimates stand to be corrected, based on whatever hypothesis is seen to be more defendable.

Basic Considerations

The filling of mine voids and chemical diversification of the contained polluted water, after cessation of dewatering by the miners, comprise two main stages:

1. Filling stage: It represents the initial filling of the void largely by surface ingress of meteoric water.

   a) Groundwater seeping through improperly-sealed mine void walls may contribute to the filling, but this process is gradually diminished by the increasing hydraulic equilibrium as the mine void levels approach the surrounding groundwater table.

   b) The resulting initial void water is strongly polluted with the oxidation products of pyrite and related sulphide that are present on the void walls. In general, it could be expected that the contamination is directly proportional to the exposed surface area of void walls. Younger (1997) refers to water that initially filled the void as the *vestigial component.*

   c) Polluted surface ingress will add to the salt load of the vestigial component. Younger (1997) refers to this polluted water that continuously forms at the water table as the *juvenile component*. In the case of the Witwatersrand, polluted surface waters, e.g. mine dump run-off, must be added to the juvenile component. This augmented product is here referred to as the *surface-enhanced juvenile component*.

      i. The surface area contribution to the juvenile component reduces as filling of the void proceeds due to the reduction in exposed reaction surface. Consequently, the early-formed juvenile component is probably more polluted than that formed later.

2. Decant stage: When the void is filled, decanting begins at the lowest elevation where the void vents to surface. From this time onward, unless disturbed, the decant volume balances the surface ingress volume (as also mentioned by Younger, 1997). Several unknowns during the decant stage exist and several assumptions need to be made. These include:

   a) Only surface-enhanced juvenile water enters the void through surface ingress after decant started.

   b) The path followed by the ingress water to the decant site will tend to follow the path of least flow resistance, and becomes channelised. Unless major convection is triggered by the ingress, this path is probably along the shallow, less-restricted, void openings. The decant will most probably be of a mixture of vestigial and surface-enhanced juvenile water;

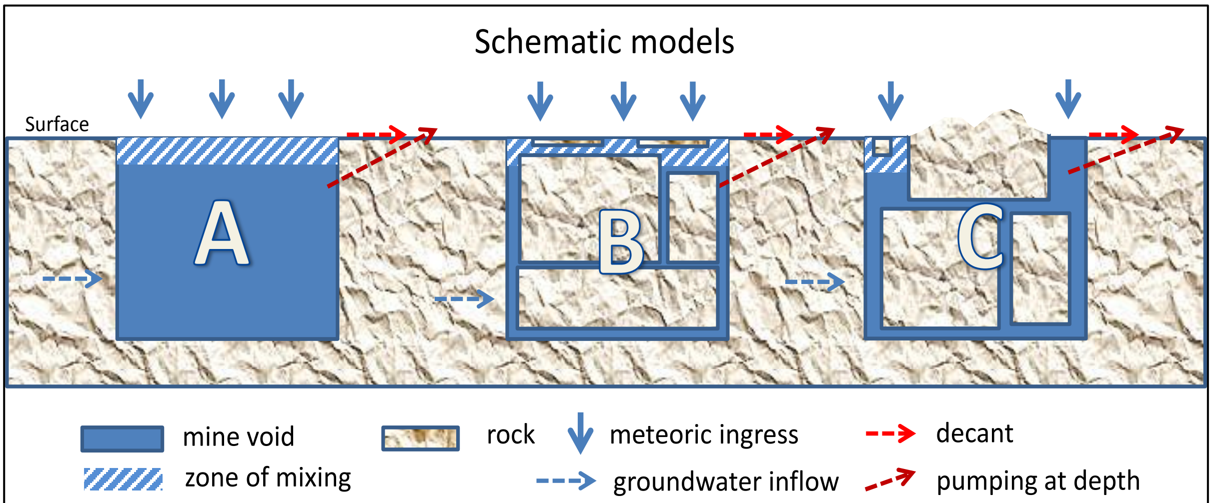
   c) If pumping from levels deeper than the decant level is invoked, the flow path of the water may be altered depending on the void layout;

d) Under conditions where shallow flow is restricted, channelling through the deep void may be forced. Deep void water is expelled to the decant point and is largely replaced by the surface-enhanced juvenile component. In this instance mostly vestigial water will decant during the earlier decant stages;

e) The possible role of heat convection is regarded as important, but its true effect is not known. The geothermal gradient in the Witwatersrand Basin is about 10°C per km, which implies an estimated 30° temperature differential between surface and depths of 3 km. Under these conditions heat convection is expected to initiate spontaneously, which depending restrictions in the mine void layout, may supply a constant stream of deep void water into the mixing zone.

Schematic profiles depicting the decant possibilities and in-void mixing are given in **Figure 3**. With this background, the three basins are investigated individually below, in an attempt

- To limit the water quality to be expected from each during the pumping exercise, and also
- To illuminate the choice of pollution data presented by Shango Solutions in the DWA Report.



Model A: Open void; not realistic.

Model B: Typical mine void – more interconnected at shallow levels, restricted at depth; zone of shallow active circulation and mixing expected while decanting; this zone will be replaced to deeper levels with deep level pumping. (Example: East Rand Basin)

Model C: Deep level circulation forced by topography and mine void outlay; zone of shallow mixing will increase in areas distal to decant but will be much reduced close to decant/pumping site. (Example: West Rand Basin)

NB: Goundwater flow probably insignificant due to hydraulic equilibrium, but some dilution of fouled water is to be expected.

Figure 3: Proposed models for in-void water flow

Western Basin

As a general observation, the Western Basin data is temporally well represented but has a limited chemical diversity of the analysed salt load. However, the fact that there is a rather complete record of void water flowing from the BRI and 17 and 18 Winzes over about

10 years, allowed inferences to be made on the temporal variation of the water quality of the Western Basin void.

The water data used for the Western Basin is summarised in **Table 1** (number of records) and **Table 2** and **Table 3** (values contained in the records). Only the samples marked in green in **Table 1** were utilised to determine the percentiles quoted in the DWA Report. The remaining samples, excepting the RE data, were used to prepare the diagrams (DWA Report, **Figures 6.19** to **6.21**). The RE data dates back to 2006 and from the discussion to follow, the reason for its omission will become clear.

Table 1: Datasets and sampling dates for Western Basin.

<table>
<tr><th>Locality</th><th>n</th><th>From</th><th>To</th><th>Source</th></tr>
<tr><td colspan="4">Surface</td><td rowspan="28">Rand Uranium</td></tr>
<tr><td>Charles Fourie</td><td>58</td><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td>Downstream Brick Dam</td><td>58</td><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td>Entrance to Lion Camp</td><td>58</td><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td rowspan="6">Hippo Pool</td><td rowspan="6">297</td><td>Jan-05</td><td>Dec-05</td></tr>
<tr><td>Jan-06</td><td>Dec-06</td></tr>
<tr><td>Jan-07</td><td>Dec-07</td></tr>
<tr><td>Jan-08</td><td>Dec-08</td></tr>
<tr><td>Dec-08</td><td>Aug-09</td></tr>
<tr><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td rowspan="5">Inflow to Game Reserve</td><td rowspan="5">207</td><td>Jan-05</td><td>Dec-05</td></tr>
<tr><td>Jan-06</td><td>Dec-06</td></tr>
<tr><td>Jan-07</td><td>Dec-07</td></tr>
<tr><td>Jan-08</td><td>Dec-08</td></tr>
<tr><td>Dec-08</td><td>Aug-09</td></tr>
<tr><td>Inlet to Game Reserve Seepage</td><td>58</td><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td>Krugersdorp Game Reserve</td><td>100</td><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td>Lion Camp</td><td>58</td><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td colspan="4">Decanting Void</td></tr>
<tr><td rowspan="6">Black Reef Incline</td><td rowspan="6">297</td><td>Jan-05</td><td>Dec-05</td></tr>
<tr><td>Jan-06</td><td>Dec-06</td></tr>
<tr><td>Jan-07</td><td>Dec-07</td></tr>
<tr><td>Jan-08</td><td>Dec-08</td></tr>
<tr><td>Dec-08</td><td>Aug-09</td></tr>
<tr><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td rowspan="6">No.17 Winze</td><td rowspan="6">277</td><td>Jan-05</td><td>Dec-05</td></tr>
<tr><td>Jan-06</td><td>Dec-06</td></tr>
<tr><td>Jan-07</td><td>Dec-07</td></tr>
<tr><td>Jan-08</td><td>Dec-08</td></tr>
<tr><td>Dec-08</td><td>Aug-09</td></tr>
<tr><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td rowspan="3">No.18 Winze</td><td rowspan="3">105</td><td>Feb-05</td><td>Nov-05</td></tr>
<tr><td>Jan-08</td><td>Dec-08</td></tr>
<tr><td>Jan-11</td><td>Mar-12</td></tr>
<tr><td colspan="4">Shaft</td><td rowspan="2">CGS</td></tr>
<tr><td>RE</td><td>17</td><td>Nov-05</td><td>Jan-06</td></tr>
<tr><td>Total no of samples</td><td>1590</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Samples used for estimation marked in green</td></tr>
</table>

Table 2: Datasets from Rand Uranium.

Mine	pH	EC	Acidity as H^+	A_Na	A_Ca	A_Fe	A_Mn	A_U	A_SO_4	WAD Cyanide
Charles Fourie	57	57	57	57	57	57	57	56	57	57
Downstream Brick Dam	58	58	58	58	58	58	58	58	58	58
Entrance to Lion Camp	58	58	58	58	58	58	58	58	58	58
Hippo Pool	296	296	58	69	58	280	68	57	296	58
Inflow to Game Reserve	265	265	58	69	58	235	66	57	265	58
Krugersdorp Game Reserve	100	100	100	100	100	98	100	70	100	100
Lion Camp	58	58	58	58	58	58	58	57	58	58
No.17 Winze	275	275	36	47	36	261	20	X	275	X
No.18 Winze	102	102	57	57	57	102	10	X	102	X
Black Reef Incline	295	295	55	66	55	295	65	X	295	X
Total no of samples	1564	1564	595	639	595	1502	560	413	1564	447

Table 3: Datasets from CGS (17 samples).

Temp	Tot Alk	P Alk	Li	Be	B	Na	Mg	Al	K
°C	mg/l $CaCO_3$	mg/l $CaCO_3$	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
17	17	17	17	17	17	17	17	17	17
Ca	V	Cr	Fe	Mn	Co	Ni	Cu	Zn	Ga
µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
17	17	17	17	17	17	17	17	17	17
As	Se	Rb	Sr	Mo	Ag	Cd	Te	Ba	Tl
µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
17	17	17	17	17	17	17	17	17	17
Pb	Bi	U	F	Cl	NO_3	SO_4			
µg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l			
17	17	17	17	17	17	17			

The Western Basin has been decanting now for more than 10 years. At 20 Mℓ/day, it amounts to 73 million m^3 over the past 10 years. This water volume, which must have entered the void largely from surface after cessation of mining, calculates to about 1.7 times the estimated total volume of the Western Basin. The question is: how did this volume of water interact with the void water? Several scenarios can be considered:

Fresh water mixing (no interaction of ingress water with void walls, i.e. weakly-polluted juvenile component)

1. The first scenario (S1; complete mixing) is where $20x10^6$ litre of fresh (100 mg/ℓ SO_4) ingress water has been incrementally and totally mixed over 10 years with $43x10^6$ m^3 of contaminated void water. If the initial void contained approximately 5 000 mg/ℓ SO_4 (as observed; **Figure 12.2**), this scenario yields a modelled[1] decant containing ca. 1 000 mg/ℓ SO_4, which is much lower than the observed number of ca. 3 000 mg/ℓ (**Table 4**).

2. In the second scenario (S2; incomplete mixing; shallow flow), the decant is the product of a channelled layer of relatively uncontaminated ("fresh") water (100 mg/ℓ SO_4) that enters from near-surface ingress points across the mining area, and which

[1] A simple numerical model based on monthly increments totalling 73 million m^3 over 10 years of fresh or contaminated ingress water mixing to varying extents with contaminated void water has been developed and used to evaluate the possible scenarios. The resulting mixing curves are typically concave-up.

flows at relatively shallow void levels to the decant point. Deep level void water is not affected (i.e. limited deep level mixing; ingress water flows laterally across the surface of the deeper void water). The system will tend towards a dynamic equilibrium (mentioned in the DWA Report, p154) which with time will reflect the long term chemical change in the ingress water quality. For ingress water containing about 100 mg/ℓ SO_4, the decant should after 10 years approach about 270 mg/ℓ SO_4. Again, this is much lower than the observed 3 000 mg/ℓ SO4 (**Table 12.4**).

Since all fresh water mixing scenarios (anything between S1 and S2) tend to underestimate the currently-observed SO_4 contents of the decant in the Western Basin, scenarios S1 and S2 are not supported by the data. Also, S1 is most likely not practically possible.

Table 4: Detail of models for the Western and Eastern Basins.

Western Basin									
Scenario	Void capacity	Ingress	Vestigial SO_4 conc.	Model ingress SO_4 conc.	Mixing zone as % of void	Period	Model decant SO4 conc.	Observed decant SO4 conc.	% Deviation Model from Observed
	Mm^3	Mℓ/day	mg/ℓ	mg/ℓ	%	Years	mg/ℓ	mg/ℓ	%
S1	43	20	5000	100	100	10	1008	3000	66.4
S2	43	20	5000	100	50	10	272	3000	90.9
S3	43	20	5000	2600	100	10	3048	3000	1.6
S4	43	20	5000	3000	50	10	3070	3000	2.3
Eastern Basin									
Scenario	Void capacity	Ingress	Vestigial EC reading	Model ingress EC reading	Mixing zone as % of void	Period	Model decant EC reading	Observed decant EC reading	% Deviation Model from Observed
	Mm^3	Mℓ/day	mS/m	mS/m	%	Years	mS/m	mS/m	%
S3	304	80	376	235	100	9.92	289	250	15.6
S4*	304	80	376	235	42	8.75	254	250	1.6
conc. = concentration; * least squares optimised									

Contaminated water mixing (continuous reaction with void walls or contamination by surface slimes dams, i.e. surface-enhanced juvenile component)

If instead of fresh water, more contaminated water is used to simulate the ingress component, the currently observed SO_4 data can be broadly simulated. There are two scenarios again (**Table 4**).

3. Scenario S3: assuming again complete mixing conditions and a constant composition of the inflowing water over the 10 year period, the SO_4 content of the ingress water calculates to ca. 2 600 mg/ℓ SO_4, i.e. to yield 3 000 mg/ℓ in the decant from an initial 5 000 mg/ℓ SO_4 in the void (**Table 4**).

4. Scenario S4: under incomplete mixing and shallow flow conditions, the decant water will approach the same composition as that of the ingress water, i.e. 3 000 mg/ℓ SO_4, regardless of the void water quality (**Table 4**). Obviously, the smaller the fraction of void water mixing with the ingress component, the sooner the decant will reach the

composition of the ingress water. For 10% of the void mixing with the ingress, the equilibrium is reached after about 4 years.

Although the absolute numbers for scenarios S3 and S4 are broadly comparable to those observed, the resulting dilution curves are concave-up and not convex-up as illustrated in **Figure 4**. Moreover, as for S1, S3 is probably practically impossible.

Further consideration of these options led to a fifth scenario.

Rinsing-by-replacement hypothesis

5. Scenario S5: The fifth scenario represents a model of large-scale rinsing/flushing by replacement of the mine void water. In this scenario (Model C in **Figure 3**), deep vestigial void water is forced to the decant site for a lengthy period. The decant maintains a strongly polluted salt load until most of the void is replaced by the ingress component. The Western Basin data conforms to this scenario (**Figure 4**). The water that decanted prior to 2009 is interpreted to be dominantly vestigial water that was forced directly out of the deep void system. However, from the point where the filling ratio (i.e. the void water replacement ratio) approaches one (about February 2008, **Figure 4)**, the decanting void water gradually becomes diluted and hence the convex-up pattern. Conceivably, prolonged flow, if channelling through the deep mine void continues, will ultimately produce a mixing line between any remaining vestigial water and enhanced juvenile water. Ultimately the decant will reflect the chemistry of the ingress component: less contaminated ingress water, mixing with increasingly diluted residual void water, decants increasingly less contaminated water until the decant and ingress qualities are comparable.

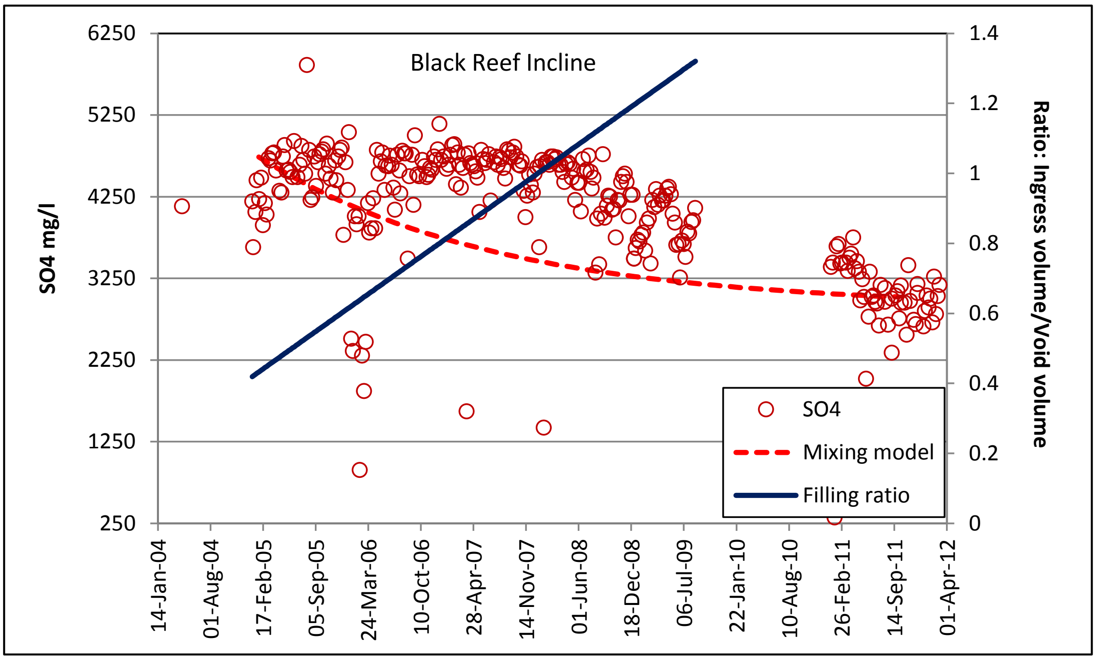


Figure 4: Trend of water quality improvement as represented by SO_4 (mg/ℓ) for the Western Basin. Blue line is the proposed void water replacement curve, and red dotted line is a linear mixing line (see text for detail).

It is evident from the above analysis that:

1. There are two possible scenarios to consider for the Western Basin. The decant water could have developed its current quality

    a) by simple mixing of the void water with ingress water if the ingress water is strongly contaminated (S3 and S4), or

    b) if the contaminated void water is being flushed/replaced from the void by less contaminated ingress water further back in the basin (S5).

    Although either of these scenarios could yield the observed numbers for the Western Basin, S5 is the only model that can produce a convex-up decant progression line, and is thus supported by the observed data.

2. In the preferred S5 scenario, the Basin currently appears to have been rinsed quite extensively since decant started, and it is unlikely that the highly polluted vestigial water will reappear. Further pumping, even if somewhat aggressive in the early days, may initially disturb the presumed dynamic equilibrium but the system will probably rapidly return to the chemical levels currently observed, or even better.

3. It is expected that the water chemistry of the Western Basin at the current decant points will from now on proceed to a simple mixing scenario (S4) and gradually clean itself in the long term. Complete cleaning depends on quality of the surface-enhanced juvenile component and may take several decades, or even centuries as proposed by Younger (1997).

4. If, as projected, even further improvement of the water qualities could occur over time (as referred to in the DWA Report, as well as by many previous investigators), the water quality numbers put forward in the DWA Report are construed to be reasonable estimates.

All these factors considered, and including the risk of the expense of overestimation, only the coherent datasets for the periods 2011 and 2012 for the BRI, and 17 and 18 Winzes were selected to evaluate the water qualities for the Western Basin (DWA Report, **Tables 6.10** to **6.12**). This should explain the observed difference between the water quality numbers reported by Shango Solutions and those previously given by the TCTA. It would appear that the TCTA used historic data (< 2005) without considering the temporal trends of water quality improvement.

Central Basin

The Central Basin is currently in the process of creating the vestigial component. It poses a special challenge in that decanting has not started and the water quality information is scattered and not abundant. The available data has a reasonably complete chemical spread but is temporally limited. The incomplete nature of the data prevented any inferences on temporal variations.

The data used for this basin, which was accrued during a sampling campaign executed by Shango Solutions on behalf of the CGS, is listed in **Table 5**. The chemical spread contained in the dataset is the same as that listed in **Table 3** above.

The "Underground" samples in **Table 5** have been used as representative of the void water (DWA Report, **Table 7.13**), whereas the remaining data reflect shaft and surface samples (DWA Report, **Tables 7.11** and **7.12**). It is anticipated that the shaft waters may not be good estimators of void water chemistry because of surface contamination and possible reactions with the shaft linings.

The Underground data (DWA Report, **Table 7.13**) is probably the best broad estimate available for the void water quality of the Central Basin.

Table 5: Datasets from CGS for the Central Basin.

Locality	n	Sampled	Source
Shafts			CRG
CD 03Vent	14	2005	
CD 04	23		
CM 14	7		
CM 17	13		
DRD 06	23		
DRD Circular	18		
ERPM Central	1		
SJ Catlin	8		
SJ Howard	13		
Underground			
EUEU1	6	2005-2006	
EU-EU2	6		
Surface			
ER-ER1 to 20b	23	2005-2006	
Not used			
EU EU3	2	Depth suspect	
ER ER 20	2	Chemistry suspect	
Total no of samples	155		

Eastern Basin

The chemical spread of the Eastern Basin data is variable and the temporal reach is limited for most mines, except Grootvlei Mine. The Eastern Basin has not reached the decant stage and, for long periods of time, partly treated water has been discarded in the same hydrological catchment system from which it was extracted. This situation probably caused some prolonged recycling of treated void water back into the mine void (**Table 8.4**, DWA Report).

The water quality data obtained for the Eastern Basin is summarised in **Table 6**. The data is quite restricted in both chemical and temporal range, and detailed analysis of possible long-term variations is not possible. All the data has been used to calculate the overall chemical variation as reported in the DWA Report (**Tables 8.11** and **8.12**). In **Table 8.12** the inclusion of treated water may have biased the pH, Fe and SO_4 values to some extent, but this effect is discounted for in the data in **Table 8.13**. Only the "Underground" mine data was used to construct **Table 8.13** of the DWA Report (the pre-1999 data was excluded), which is also seen as the best estimate of the void water.

The data spread for the CGS data is the same as in **Table 3**. The Grootvlei Mine data is incomplete in terms of chemical spread as indicated in **Table 8.12** in the DWA Report.

If the same principles discussed for the Western Basin are applied to the Grootvlei Mine data of the Eastern Basin, it is evident that a simple linear two-component mixing model (red dotted line, **Figure 5**) explains the observed EC data quite well. The least squares-optimised model yields a value of 376 mS/m for the initial void water (vestigial) and 235 mS/m for the ingress component (i.e. surface-enhanced juvenile component), assuming the total void volume to be 304 Mm^3 and the daily ingress volume at 80 Mℓ (**Table 4**). Furthermore, the projected endpoints of pH (7-8), EC (~250 mS/m) and Fe (<50 mg/ℓ) of the proposed mixing curves (only EC shown here) approach the composition of the discharged treated water chemistry (pH = 7.5; EC = 250 mS/m; Fe <5 mg/ℓ). This suggests that the treated water is involved in the Eastern Basin dilution process.

Table 6: Datasets from CGS for the Eastern Basin.

Mine	Sampling Type	n	Sampled	Source
Underground				
East Geduld	Underground	12	2005	CGS
Geduld	Underground	11	2005	
Government Areas	Underground	12	2005	
Grootvlei	Underground	4	2005	
Grootvlei	Underground	127	1997-2008	Grootvlei
Flume, treated discharge, daily				
Grootvlei	Flume, treated discharge, daily	3497	1999-2008	
Not used				
Unknown		1		
Total no of samples		3664		

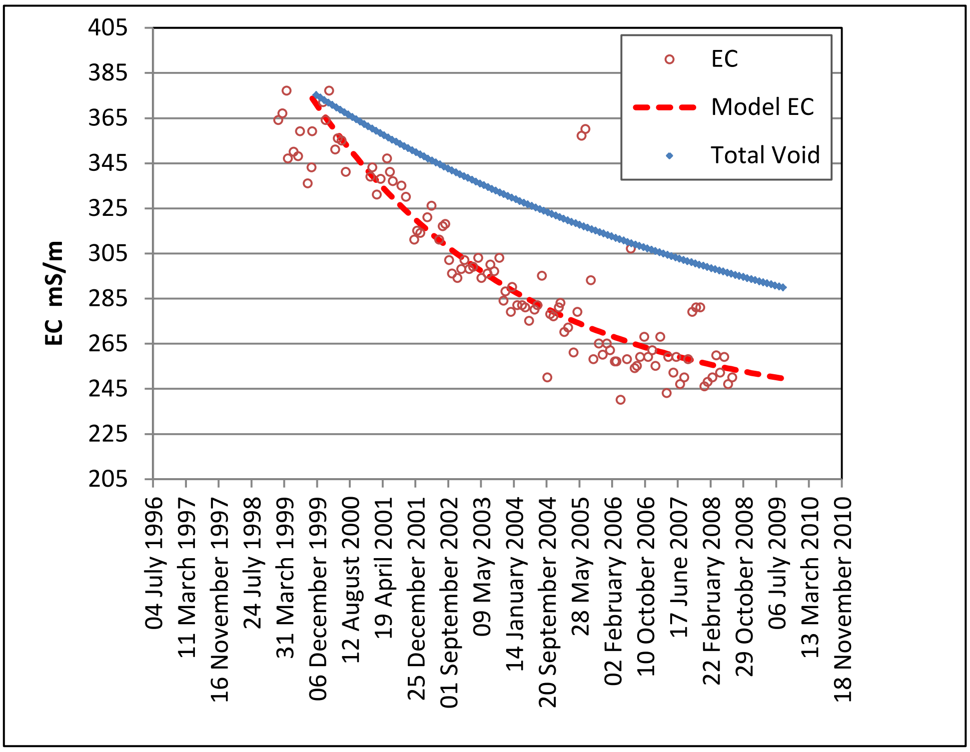


Figure 5: Water quality improvement at Grootvlei Mine. Red dotted line is a best fit model based on linear two-component mixing with only ca. 40 % of the void participating. Blue line assumes a 100 % participation of the void volume.

More importantly, still, is that the numerical model also requires that only about 40 % of the total void volume of the East Rand Basin participated in the mixing process. If a 100 % of the void volume had participated, the blue line in **Figure 5** would have developed. This observation, and the fact that pumping at Grootvlei was from relatively shallow levels, suggest that only the upper part of the void probably participated in the mixing process that caused the observed gradual change of the East Rand void water chemistry.

In an attempt to probe the contribution made to the mixing zone by slow heat convection in the deep void, a simple three-component linear mixing model has been developed. In this model, the vestigial and surface-enhanced juvenile components are actively mixed in the shallow mixing zone, while a relatively small fraction of the deep void water is allowed to constantly exchanging salt load with the shallow mixing volume. The latter implies that the deep void water is gradually becoming more diluted. A least squares-optimised model yielded the following results:

- Total void volume = 304 Mm^3;
- Daily ingress = 80 Mℓ;
- EC of the vestigial component = 371 mS/m;
- EC of surface-enhanced juvenile component = 180 mS/m;
- % of void volume participating in the shallow mixing zone = 63; and
- % of deep void volume (below active mixing zone) turned over by heat convection = 0.8.

This model implies that a small fraction of deep void water might indeed continuously be exchanging its salt load with the shallow mixing zone. However, analysis of variance calculations yield an insignificant F value for the estimated percentage of deep void circulation, and this number is therefore construed qualitative rather than quantitative. More work is needed to quantify this process.

Finally, the data presented here for the Eastern Basin is indicative of a gradually diluting system. High salt loads observed when pumping was still active is regarded to reflect a high fraction of early-formed juvenile component which will be more polluted than a mixture of this early-formed juvenile component and relatively unpolluted ingress water that fills the basin. As the void fills, the exposed surface area over which the juvenile component can form reduces substantially. This effective reduction in reaction surface will also gradually reduce the potential salt load attributable to the juvenile component. Consequently, the proposed salt loads proposed in the DWA Report by Shango Solutions are regarded as reasonable estimates of what can be expected in the long run during pumping.

Summary

The filling models for the Western and Eastern Basins are summarised in **Figure 6**. These models imply that the worst water qualities to be expected from these basins have already been diluted or expelled. However, it stand to reason that if pumping is commenced from very deep levels, a deep void channelised flow pattern as envisaged by Model C could be initiated. It is doubtful though that the water qualities will be worse that what has been estimated and reported in the DWA Report.

Conclusions

This brief review of the water quality data utilised by Shango Solutions and reported in the DWA Report, and the way in which the data is interpreted, should explain the apparent discrepancies that exist between the water quality estimates of Shango Solutions and TCTA. These discrepancies are largely the consequence of diverse interpretation of the data combined with temporal variation in the water qualities resulting from diverse processes.

It would appear that two different scenarios are dealt with in the Western and Eastern Basins. The Western Basin, being in the decant phase, is in an advanced stage of rinsing of the void water through deep level flow. The data from the Eastern Basin suggests simple mixing, involving also treated water, within the mine void. The latter suggests large-scale recycling, supporting the notion that treated water should ideally be prevented from flowing back into the basin. The expected salt load in the water from the Central Basin is less certain due to an inadequate sample spread.

In view of these models, the salt loads for the three main basins, proposed by Shango Solutions in the DWA Report, are regarded as reasonable estimates of what can be expected during pumping.

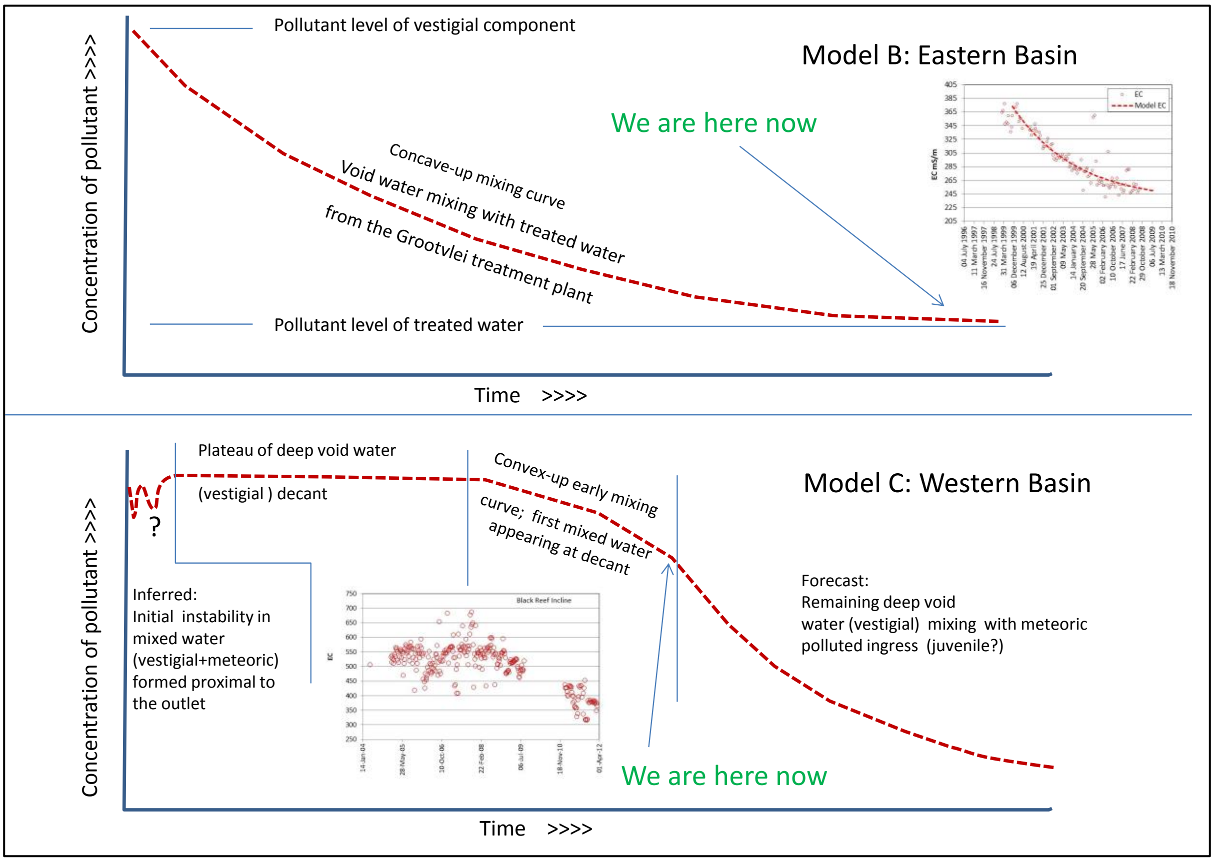


Figure 6: Simplified filling models for the Eastern and Western Basins (models as referred to in Figure 3).

References

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