# Geochemical Assessment for the proposed West Wits Mining Project

Robert N Hansen
GeoDyn Systems

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# Geochemical Assessment for the proposed West Wits Mining Project

**Authored by:**

Robert N Hansen (PhD (Geology) Pri.Sci.Nat – 400125/08)

# EXECUTIVE SUMMARY

GeoDyn Systems (GeoDyn) was requested by Noa Agencies (Noa) to conduct a geochemical risk assessment for the open pit gold mine waste rock material as part of the proposed West Wits mining project. The mine will only generate waste rock as a mineral waste as only primary processing will occur on site. All run of mine material will be transported to an existing processing plant off-site for concentrating of ore and therefore there will be no tailings storage facility on site.

The objectives of the geochemical assessment are to:

a. Conduct a waste classification of the waste rock.
b. Determine the likelihood of the development of acid mine drainage (AMD) conditions from the waste material.
c. Determine the likelihood of leaching of potential contaminants from the waste rock material.

The waste is classified as Type 3, thus requiring a Class C engineered barrier system. However, none of the constituents in the leach test exceeded the regulatory guideline values. In addition, the geochemical model indicated that the waste rock is comprised of minerals which are very stable in the specific mining environment being considered. In addition, the waste rock itself as well as the secondary mineral products forming very slowly as the waste rock minerals weather and thus have the capacity to remove contaminants from solution through the process of adsorption. It is possible that nitrate may leach from the waste rock material, but this is not due to the composition of the waste rock material itself. It is due to process water which may contain nitrate due to the use of ammonium nitrate explosives, although no blasting will be take place in the open pit mining areas. Blasting will only take place as part of the underground mining operations, where all waste rock created during the development of the mining process, will remain underground. The nitrate in the mine process water is however an operational and not post-operational issue.

The waste rock material contains no iron sulphide minerals. Therefore, the risk of the formation of acid mine drainage conditions due to the waste rock material is negligible.

Due to the stability of the waste rock material as well as the negligible risk of the formation of acid mine drainage conditions, it is recommended that the waste rock be re-classified as Type 4, which is inert.

The results indicate that the significance of both potential impacts rate as *Very Low*. The cumulative impacts rate as *Low*. This is predominantly because of the fact that the development of AMD conditions as well as the leaching of contaminants from the waste rock is unlikely.

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## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| **ABA** | Acid Base Accounting |
| **AMD** | Acid Mine Drainage |
| **NAG** | Net Acid Generation |
| **NEMWA** | National Environmental Waste Act |
| **R635** | Regulation 635 (NEMWA) |
| **R636** | Regulation 636 (NEMWA) |
| **ICP-MS** | Inductively Coupled Plasma Mass Spectrometry |
| **ICP-OES** | Inductively Coupled Plasma Optical Emission Spectroscopy |
| **XRD** | X-Ray Diffraction |

# 1 INTRODUCTION

GeoDyn Systems (GeoDyn) was requested by Noa Agencies (Noa) to conduct a geochemical risk assessment for the open pit gold mine waste rock material as part of the proposed West Wits mining project. The mine will only generate waste rock as a mineral waste as only primary processing will occur on site. All run of mine material will be transported to an existing processing plant off-site for concentrating of ore and therefore there will be no tailings storage facility on site.

## 1.1 Project objectives

The objectives of the geochemical assessment are to:

a. Conduct a waste classification of the waste rock.
b. Determine the likelihood of the development of acid mine drainage (AMD) conditions from the waste material.
c. Determine the likelihood of leaching of potential contaminants from the waste rock material.

## 1.2 Project locality

The project area is located due east of the city of Johannesburg in Gauteng Province (Figure 1-1). This area has a mean annual precipitation (MAP) of 683 mm.a-1 and a mean annual evaporation (MAE) of 1 650 mm.a-1.

## 1.3 Methodology

On the 3$^{rd}$ of September 2014 the National Environmental Laws Amendment Act (NEMLAA, Act 25 of 2014), published on 2 June 2014 came into effect. These laws are an attempt by the Department of Environmental Affairs (DEA) in cooperation with other government departments, mainly the Departments of Mineral Resources (DMR) and the Department of Water and Sanitation (DWS), to legislate the waste from mining and industrial activities under one legislative system, termed the *One Environmental System*. This system is subject to certain sections under other acts, such as the Mineral and Petroleum Resources Development Act (MPRDA) and the National Water Act (NWA).

NEMLAA calls for a waste classification to be conducted according to Regulation 635 of NEMWA, which forms part of the NEMLAA legislation. To conduct the waste classification leach tests and a total analysis needs to be conducted. The leach test entails the leaching of a solid sample of waste with reagent water and the subsequent analysis of the leachate for specific components. The total analysis entails the analysis of the solid material for the total concentration of specific components that are present in the waste sample. The results of these two tests are compared to regulatory criteria and a classification is done based on the results of this comparison.

In addition, in compliance with the EIA regulations the relevant information as well as its location in the report is provided according to Table 1-1.

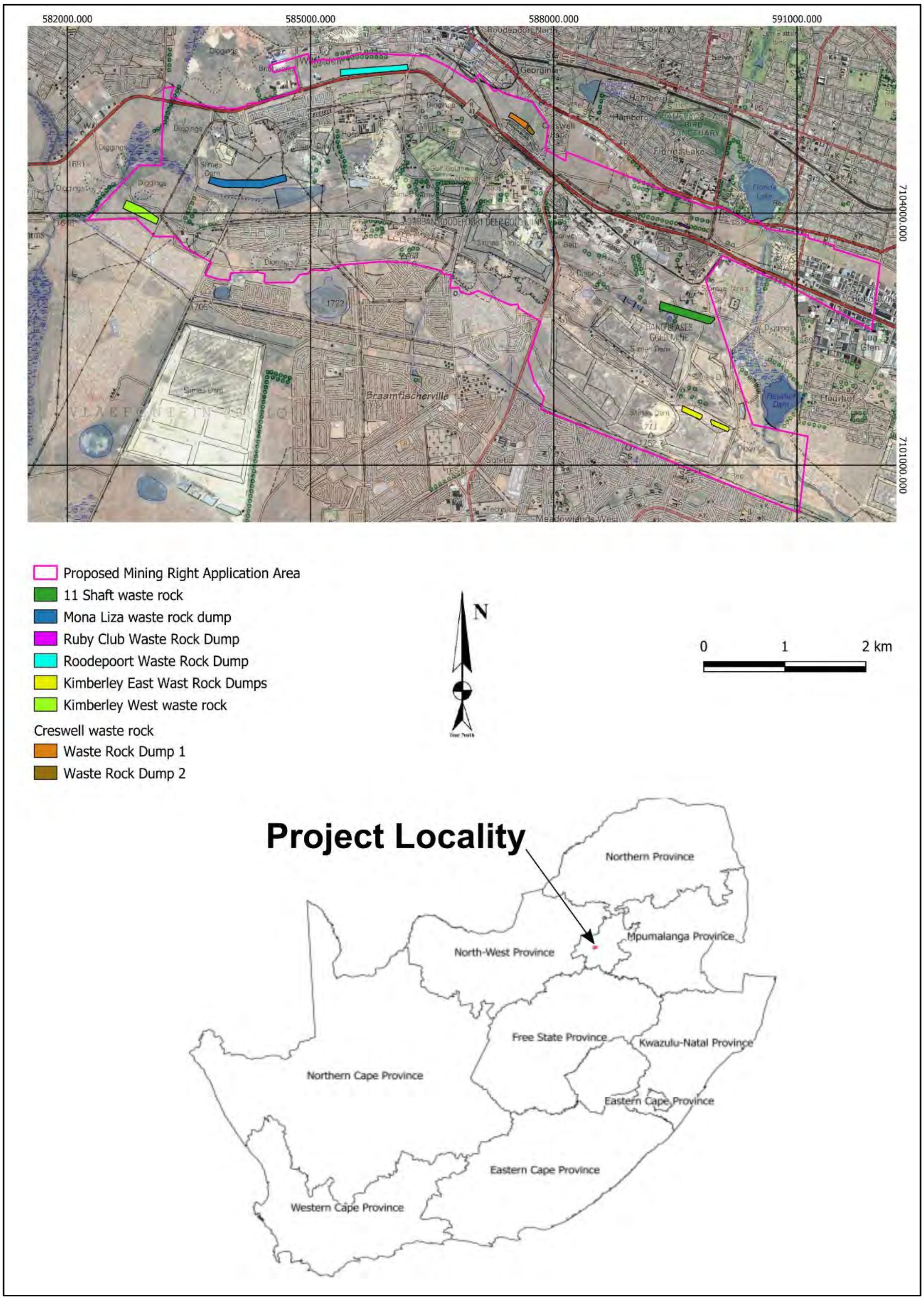


**Figure 1-1** Project locality map

**Table 1-1** Specialist study information and location

| No. | Requirement | Section in report |
|---|---|---|
| a) | Details of - | |
| (i) | The specialist who prepared the report | Appendix C |
| (ii) | The expertise of that specialist to compile a specialist report including a curriculum vitae | Appendix C |
| b) | A declaration that the specialist is independent | Appendix C |
| c) | An indication of the scope of, and the purpose for which, the report was prepared | Appendix C |
| cA) | An indication of the quality and age of base data used for the specialist report | Section 1.3 |
| cB) | A description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change | Section 5<br>Section 6**Error! Reference source not found.** |
| d) | The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment | A site visit was not conducted, as the geochemical impact study is focused on the nature of the material itself, rather than its location |
| e) | A description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used | Section 1.3 |
| f) | Details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives | Section 5<br>Section 6 |
| g) | An identification of any areas to be avoided, including buffers | N.A. |
| h) | A map superimposing the activity including the associated structure and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers | N.A. |
| i) | A description of any assumption made and any uncertainties or gaps in knowledge | Appendix A |
| j) | A description the findings and potential implication\s of such findings on the impact of the proposed activity, including identified alternatives on the environment or activities | Section 5<br>Section 6 |
| k) | Any mitigation measures for inclusion in the EMPr | Section 5 |

| No. | Requirement | Section in report |
|---|---|---|
| l) | Any conditions for inclusion in the environmental authorisation | Section 7 |
| m) | Any monitoring requirements for inclusion in the EMPr or environmental authorisation | Section 6 |
| n) | A reasoned opinion - | |
| (i) | As to whether the proposed activity, activities or portions thereof should be authorised | Section 6<br>Section 7 |
| (iA) | Regarding the acceptability of the proposed activity or activities | |
| (ii) | If the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan | Section 5<br>Section 6<br>Section 7<br>Section 8 |
| o) | A description of any consultation process that was undertaken during the course of preparing the specialist report | N.A. |
| p) | A summary and copies of any comments received during any consultation process and where applicable all responses thereto; and | N.A. |
| q) | Any other information requested by the competent authority | N.A. |

As part of the waste classification and assessment of the risks from a particular waste, the DEA subscribes to the source-pathway-receptor analysis methodology, which is international best practice.

The use of this assessment methodology allows the analysis of the full cycle of a potential contaminant to be evaluated within the proper scientific framework so that risks can be realistically assessed and proper mitigation measures proposed. As opposed to a blanket "one-size-fits-all" approach which often leads to the application of non-sustainable solutions resulting in large capital expenditure but no real mitigate value. For the quantification of medium to long term geochemical risks associated with the waste material, i.e. mine tailings and overburden, numeric geochemical modelling is used as a tool. This modelling entails the use of established thermodynamic and kinetic principles to calculate risks over time. The internationally validated geochemical modelling software package PHREEQC is used for this purpose.

A total of 20 samples were collected for this study, which were composited into representative samples for laboratory analysis at an accredited laboratory, namely Metron. The following laboratory analyses were conducted for the waste classification, assessment of the likelihood of acid mine drainage (AMD) and the leach potential of contaminants from the waste rock dumps:

- Acid Base Accounting (ABA) analysis

- Sulphur speciation analysis
- Carbon speciation analysis
- Leach test according to NEMWA Regulation 635 (R635)
- Whole rock analysis (Aqua Regia) according to R635
- Mineralogical analysis (X-Ray Diffraction)

# 2 WASTE CLASSIFICATION

## 2.1 11 Shaft

### *2.1.1 Leachate analysis*

The leachate assessment data is shown in **Table 2-1**. The assessment indicates that none of the parameters analysed is leached in concentrations that exceed the regulatory values of R635 in the Waste Rock 2 sample. Arsenic leaches in concentrations exceeding the LCT0 value of R635.

### *2.1.2 Total concentration analysis*

The total concentration assessment data is shown in Table 2-2. The assessment indicates that arsenic concentrations in the 11 Shaft waste rock samples 1 and 2 exceed the TCT0 value, but is less than the TCT1 value, of R635. Copper in the waste rock sample exceeds the TCT0 value of R635.

### *2.1.3 Waste classification results*

Based on the criteria in Section 7 of R635, the 11 Shaft waste rock is classified as Type 3, which according to R636 requires a Class C engineered barrier system.

## 2.2 Kimberley East

### *2.2.1 Leachate analysis*

The leachate assessment data is shown in Table 2-3. The assessment indicates that none of the parameters analysed is leached in concentrations that exceed the regulatory values of R635.

### *2.2.2 Total concentration analysis*

The total concentration assessment data is shown in Table 2-4. The assessment indicates that only arsenic concentrations in the Kimberley East waste rock exceeds the TCT0 value, but is less than the TCT1 value, of R635.

### *2.2.3 Waste classification results*

Based on the criteria in Section 7 of R635, the Kimberley East waste rock is classified as Type 3, which according to R636 requires a Type C engineered barrier system.

**Table 2-1** 11 Shaft waste rock leachate analysis data

| Inorganic Waste constituents | Abbreviation | R635 Leach Concentration Threshold Values LCT0 | LCT1 | LCT2 | LCT3 | 11 Shaft Waste Rock |
|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | mg/l | mg/l |
| **Metal Ions** | | | | | | |
| **Arsenic** | **As** | 0.01 | 0.5 | 1 | 4 | 0.037 |
| **Boron** | **B** | 0.5 | 25 | 50 | 200 | <0.01 |
| **Barium** | **Ba** | 0.7 | 35 | 70 | 280 | <0.002 |
| **Cadmium** | **Cd** | 0.003 | 0.15 | 0.3 | 1.2 | <0.002 |
| **Cobalt** | **Co** | 0.5 | 25 | 50 | 200 | <0.002 |
| **Chromium (Total)** | **Cr(Total)** | 0.1 | 5 | 10 | 40 | <0.002 |
| **Chromium (VI)** | **Cr(VI)** | 0.05 | 2.5 | 5 | 20 | <0.002 |
| **Copper** | **Cu** | 2.0 | 100 | 200 | 800 | <0.002 |
| **Mercury** | **Hg** | 0.006 | 0.3 | 0.6 | 2.4 | <0.002 |
| **Manganese** | **Mn** | 0.5 | 25 | 50 | 200 | 0.02 |
| **Molybdenum** | **Mo** | 0.07 | 3.5 | 7 | 28 | <0.002 |
| **Nickel** | **Ni** | 0.07 | 3.5 | 7 | 28 | <0.002 |
| **Lead** | **Pb** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Antimony** | **Sb** | 0.02 | 1.0 | 2 | 8 | <0.002 |
| **Selenium** | **Se** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Vanadium** | **V** | 0.2 | 10 | 20 | 80 | <0.002 |
| **Zinc** | **Zn** | 5.0 | 250 | 500 | 2 000 | 0.007 |
| **Inorganic Anions** | | | | | | |
| **Total Dissolved Solids** | **TDS** | 1 000 | 12 500 | 25 000 | 100 000 | 6 |
| **Chloride** | **Cl** | 300 | 15 000 | 30 000 | 120 000 | <5 |
| **Sulphate** | **$SO_4$** | 250 | 12 500 | 25 000 | 100 000 | 3 |
| **Nitrate as Nitrogen** | **$NO_3$-N** | 11 | 550 | 1 100 | 4 400 | <0.2 |
| **Fluoride** | **F** | 2 | 75 | 150 | 600 | <0.1 |
| **Cyanide (Total)** | **$CN^-$(Total)** | 0 | 4 | 7 | 28 | 0 |

**Table 2-2** 11 Shaft waste rock total concentration analysis data

| Waste constituents | Abbreviation | R635 Total Concentration Threshold Values TCT0 mg/kg | TCT1 mg/kg | TCT2 mg/kg | 11 Shaft Waste Rock mg/kg |
|---|---|---|---|---|---|
| **Metal Ions** | | | | | |
| Arsenic | As | 5.8 | 500 | 2 000 | 72 |
| Boron | B | 150 | 15 000 | 60 000 | <4 |
| Barium | Ba | 62.5 | 6 250 | 25 000 | 7 |
| Cadmium | Cd | 7.5 | 260 | 1 040 | <2 |
| Cobalt | Co | 50 | 5 000 | 20 000 | 6 |
| Chromium (Total) | Cr(Total) | 46 000 | 800 000 | n.a | 35 |
| Chromium (VI) | Cr(VI) | 6.5 | 500 | 2 000 | <2 |
| Copper | Cu | 16.0 | 19 500 | 78 000 | 19 |
| Mercury | Hg | 0.93 | 160 | 640 | <1 |
| Manganese | Mn | 1 000 | 25 000 | 100 000 | 37 |
| Molybdenum | Mo | 40 | 1 000 | 4 000 | <2 |
| Nickel | Ni | 91 | 10 600 | 42 400 | 17 |
| Lead | Pb | 20 | 1 900 | 7 600 | 9 |
| Antimony | Sb | 10 | 75 | 300 | <2 |
| Selenium | Se | 10 | 50 | 200 | <2 |
| Vanadium | V | 150 | 2 680 | 10 720 | 5 |
| Zinc | Zn | 240.0 | 160 000 | 640 000 | 14 |
| **Inorganic Anions** | | | | | |
| Fluoride | F | 100 | 10 000 | 40 000 | <20 |
| Cyanide (Total) | $CN^-$(Total) | 14 | 10 500 | 42 000 | 0 |

## 2.3 Mona Liza

### *2.3.1 Leachate analysis*

The leachate assessment data is shown in Table 2-5. The assessment indicates that none of the parameters analysed is leached in concentrations that exceed the regulatory values of R635 in the Waste Rock 2 sample. Arsenic leaches in concentrations exceeding the LCT0 value of R635.

### *2.3.2 Total concentration analysis*

The total concentration assessment data is shown in Table 2-6. The assessment indicates that arsenic concentrations in the Mona Liza waste rock sample exceed the TCT0 value, but is less than the TCT1 value, of R635. Copper in the Waste Rock sample exceeds the TCT0 value of R635.

**Table 2-3** Kimberley East waste rock leachate analysis data

| Inorganic Waste constituents | Abbreviation | R635 Leach Concentration Threshold Values LCT0 | LCT1 | LCT2 | LCT3 | Kimberley East Waste Rock |
|---|---|---|---|---|---|---|
| | | mg/ℓ | mg/ℓ | mg/ℓ | mg/ℓ | mg/ℓ |
| **Metal Ions** | | | | | | |
| **Arsenic** | **As** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Boron** | **B** | 0.5 | 25 | 50 | 200 | <0.01 |
| **Barium** | **Ba** | 0.7 | 35 | 70 | 280 | <0.002 |
| **Cadmium** | **Cd** | 0.003 | 0.15 | 0.3 | 1.2 | <0.002 |
| **Cobalt** | **Co** | 0.5 | 25 | 50 | 200 | <0.002 |
| **Chromium (Total)** | **Cr(Total)** | 0.1 | 5 | 10 | 40 | <0.002 |
| **Chromium (VI)** | **Cr(VI)** | 0.05 | 2.5 | 5 | 20 | <0.002 |
| **Copper** | **Cu** | 2.0 | 100 | 200 | 800 | <0.002 |
| **Mercury** | **Hg** | 0.006 | 0.3 | 0.6 | 2.4 | <0.002 |
| **Manganese** | **Mn** | 0.5 | 25 | 50 | 200 | 0.003 |
| **Molybdenum** | **Mo** | 0.07 | 3.5 | 7 | 28 | <0.002 |
| **Nickel** | **Ni** | 0.07 | 3.5 | 7 | 28 | <0.002 |
| **Lead** | **Pb** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Antimony** | **Sb** | 0.02 | 1.0 | 2 | 8 | <0.002 |
| **Selenium** | **Se** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Vanadium** | **V** | 0.2 | 10 | 20 | 80 | <0.002 |
| **Zinc** | **Zn** | 5.0 | 250 | 500 | 2 000 | <0.002 |
| **Inorganic Anions** | | | | | | |
| **Total Dissolved Solids** | **TDS** | 1 000 | 12 500 | 25 000 | 100 000 | 15 |
| **Chloride** | **Cl** | 300 | 15 000 | 30 000 | 120 000 | <5 |
| **Sulphate** | **$SO_4$** | 250 | 12 500 | 25 000 | 100 000 | 3.71 |
| **Nitrate as Nitrogen** | **$NO_3$-N** | 11 | 550 | 1 100 | 4 400 | <0.2 |
| **Fluoride** | **F** | 2 | 75 | 150 | 600 | <0.1 |
| **Cyanide (Total)** | **$CN^-$(Total)** | 0 | 4 | 7 | 28 | < 0.005 |

**Table 2-4** Kimberley East waste rock total concentration analysis data

| Waste constituents | Abbreviation | R635 Total Concentration Threshold Values TCT0 | TCT1 | TCT2 | Kimberley East Waste Rock |
|---|---|---|---|---|---|
| | | *mg/kg* | *mg/kg* | *mg/kg* | *mg/kg* |
| **Metal Ions** | | | | | |
| **Arsenic** | **As** | 5.8 | 500 | 2 000 | 21 |
| **Boron** | **B** | 150 | 15 000 | 60 000 | <4 |
| **Barium** | **Ba** | 62.5 | 6 250 | 25 000 | 9 |
| **Cadmium** | **Cd** | 7.5 | 260 | 1 040 | <2 |
| **Cobalt** | **Co** | 50 | 5 000 | 20 000 | 3 |
| **Chromium (Total)** | **Cr(Total)** | 46 000 | 800 000 | n.a | 27 |
| **Chromium (VI)** | **Cr(VI)** | 6.5 | 500 | 2 000 | <2 |
| **Copper** | **Cu** | 16.0 | 19 500 | 78 000 | 7 |
| **Mercury** | **Hg** | 0.93 | 160 | 640 | <1 |
| **Manganese** | **Mn** | 1 000 | 25 000 | 100 000 | 20 |
| **Molybdenum** | **Mo** | 40 | 1 000 | 4 000 | <2 |
| **Nickel** | **Ni** | 91 | 10 600 | 42 400 | 3 |
| **Lead** | **Pb** | 20 | 1 900 | 7 600 | 4 |
| **Antimony** | **Sb** | 10 | 75 | 300 | <2 |
| **Selenium** | **Se** | 10 | 50 | 200 | <2 |
| **Vanadium** | **V** | 150 | 2 680 | 10 720 | 4 |
| **Zinc** | **Zn** | 240.0 | 160 000 | 640 000 | 7 |
| **Inorganic Anions** | | | | | |
| **Fluoride** | **F** | 100 | 10 000 | 40 000 | <10 |
| **Cyanide (Total)** | **$CN^-$(Total)** | 14 | 10 500 | 42 000 | < 0.1 |

**Table 2-5** Mona Liza waste rock leachate analysis data

| Inorganic Waste constituents | Abbreviation | R635 Leach Concentration Threshold Values LCT0 | LCT1 | LCT2 | LCT3 | Mona Liza Waste Rock |
|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | mg/l | mg/l |
| **Metal Ions** | | | | | | |
| **Arsenic** | **As** | 0.01 | 0.5 | 1 | 4 | 0.037 |
| **Boron** | **B** | 0.5 | 25 | 50 | 200 | <0.01 |
| **Barium** | **Ba** | 0.7 | 35 | 70 | 280 | <0.002 |
| **Cadmium** | **Cd** | 0.003 | 0.15 | 0.3 | 1.2 | <0.002 |
| **Cobalt** | **Co** | 0.5 | 25 | 50 | 200 | <0.002 |
| **Chromium (Total)** | **Cr(Total)** | 0.1 | 5 | 10 | 40 | <0.002 |
| **Chromium (VI)** | **Cr(VI)** | 0.05 | 2.5 | 5 | 20 | <0.002 |
| **Copper** | **Cu** | 2.0 | 100 | 200 | 800 | <0.002 |
| **Mercury** | **Hg** | 0.006 | 0.3 | 0.6 | 2.4 | <0.002 |
| **Manganese** | **Mn** | 0.5 | 25 | 50 | 200 | 0.02 |
| **Molybdenum** | **Mo** | 0.07 | 3.5 | 7 | 28 | <0.002 |
| **Nickel** | **Ni** | 0.07 | 3.5 | 7 | 28 | <0.002 |
| **Lead** | **Pb** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Antimony** | **Sb** | 0.02 | 1.0 | 2 | 8 | <0.002 |
| **Selenium** | **Se** | 0.01 | 0.5 | 1 | 4 | <0.002 |
| **Vanadium** | **V** | 0.2 | 10 | 20 | 80 | <0.002 |
| **Zinc** | **Zn** | 5.0 | 250 | 500 | 2 000 | 0.007 |
| **Inorganic Anions** | | | | | | |
| **Total Dissolved Solids** | **TDS** | 1 000 | 12 500 | 25 000 | 100 000 | 6 |
| **Chloride** | **Cl** | 300 | 15 000 | 30 000 | 120 000 | <5 |
| **Sulphate** | **$SO_4$** | 250 | 12 500 | 25 000 | 100 000 | 3 |
| **Nitrate as Nitrogen** | **$NO_3$-N** | 11 | 550 | 1 100 | 4 400 | <0.2 |
| **Fluoride** | **F** | 2 | 75 | 150 | 600 | <0.1 |
| **Cyanide (Total)** | **$CN^-$(Total)** | 0 | 4 | 7 | 28 | 0 |

**Table 2-6** Mona Liza waste rock total concentration analysis data

| Waste constituents | Abbreviation | R635 Total Concentration Threshold Values | | | Mona Liza Waste Rock |
|---|---|---|---|---|---|
| | | TCT0 | TCT1 | TCT2 | |
| | | mg/kg | mg/kg | mg/kg | mg/kg |
| **Metal Ions** | | | | | |
| Arsenic | As | 5.8 | 500 | 2 000 | 72 |
| Boron | B | 150 | 15 000 | 60 000 | <4 |
| Barium | Ba | 62.5 | 6 250 | 25 000 | 7 |
| Cadmium | Cd | 7.5 | 260 | 1 040 | <2 |
| Cobalt | Co | 50 | 5 000 | 20 000 | 6 |
| Chromium (Total) | Cr(Total) | 46 000 | 800 000 | n.a | 35 |
| Chromium (VI) | Cr(VI) | 6.5 | 500 | 2 000 | <2 |
| Copper | Cu | 16.0 | 19 500 | 78 000 | 19 |
| Mercury | Hg | 0.93 | 160 | 640 | <1 |
| Manganese | Mn | 1 000 | 25 000 | 100 000 | 37 |
| Molybdenum | Mo | 40 | 1 000 | 4 000 | <2 |
| Nickel | Ni | 91 | 10 600 | 42 400 | 17 |
| Lead | Pb | 20 | 1 900 | 7 600 | 9 |
| Antimony | Sb | 10 | 75 | 300 | <2 |
| Selenium | Se | 10 | 50 | 200 | <2 |
| Vanadium | V | 150 | 2 680 | 10 720 | 5 |
| Zinc | Zn | 240.0 | 160 000 | 640 000 | 14 |
| **Inorganic Anions** | | | | | |
| Fluoride | F | 100 | 10 000 | 40 000 | <20 |
| Cyanide (Total) | $CN^-$(Total) | 14 | 10 500 | 42 000 | 0 |

### 2.3.3 *Waste classification results*

Based on the criteria in Section 7 of R635, the Mona Liza waste rock is classified as Type 3, which according to R636 requires a Type C engineered barrier system.

## 2.4 Roodepoort

### 2.4.1 *Leachate analysis*

The leachate assessment data is shown in Table 2-7. The assessment indicates that none of the parameters analysed is leached in concentrations that exceed the regulatory values of R635 in the Waste Rock 2 sample. Arsenic leaches in concentrations exceeding the LCT0 value of R635.

### 2.4.2 *Total concentration analysis*

The total concentration assessment data is shown in Table 2-8. The assessment indicates that arsenic concentrations in the Roodepoort waste rock samples 1 and 2 exceed the TCT0 value, but is less than the TCT1 value, of R635. Copper in Waste Rock sample 2 exceeds the TCT0 value of R635.

**Table 2-7** Roodepoort waste rock leachate analysis data

| | | R635 Leach Concentration Threshold Values | | | | Roodepoort Waste Rock Sample 1 | Roodepoort Waste Rock Sample 2 |
|---|---|---|---|---|---|---|---|
| Inorganic Waste constituents | Abbreviation | LCT0 | LCT1 | LCT2 | LCT3 | | |
| | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| **Metal Ions** | | | | | | | |
| Arsenic | As | 0.01 | 0.5 | 1 | 4 | 0.056 | <0.002 |
| Boron | B | 0.5 | 25 | 50 | 200 | <0.01 | <0.01 |
| Barium | Ba | 0.7 | 35 | 70 | 280 | <0.002 | <0.002 |
| Cadmium | Cd | 0.003 | 0.15 | 0.3 | 1.2 | <0.002 | <0.002 |
| Cobalt | Co | 0.5 | 25 | 50 | 200 | <0.002 | <0.002 |
| Chromium (Total) | Cr(Total) | 0.1 | 5 | 10 | 40 | <0.002 | <0.002 |
| Chromium (VI) | Cr(VI) | 0.05 | 2.5 | 5 | 20 | <0.002 | <0.002 |
| Copper | Cu | 2.0 | 100 | 200 | 800 | <0.002 | <0.002 |
| Mercury | Hg | 0.006 | 0.3 | 0.6 | 2.4 | <0.002 | <0.002 |
| Manganese | Mn | 0.5 | 25 | 50 | 200 | 0.005 | 0.006 |
| Molybdenum | Mo | 0.07 | 3.5 | 7 | 28 | <0.002 | <0.002 |
| Nickel | Ni | 0.07 | 3.5 | 7 | 28 | <0.002 | <0.002 |
| Lead | Pb | 0.01 | 0.5 | 1 | 4 | <0.002 | <0.002 |
| Antimony | Sb | 0.02 | 1.0 | 2 | 8 | <0.002 | <0.002 |
| Selenium | Se | 0.01 | 0.5 | 1 | 4 | <0.002 | <0.002 |
| Vanadium | V | 0.2 | 10 | 20 | 80 | 0.007 | <0.002 |
| Zinc | Zn | 5.0 | 250 | 500 | 2 000 | 0.003 | 0.004 |
| **Inorganic Anions** | | | | | | | |
| Total Dissolved Solids | TDS | 1 000 | 12 500 | 25 000 | 100 000 | 36 | 45 |
| Chloride | Cl | 300 | 15 000 | 30 000 | 120 000 | <5 | <5 |
| Sulphate | $SO_4$ | 250 | 12 500 | 25 000 | 100 000 | 4 | 6 |
| Nitrate as Nitrogen | $NO_3$-N | 11 | 550 | 1 100 | 4 400 | <0.2 | 0.6 |
| Fluoride | F | 2 | 75 | 150 | 600 | <0.1 | 0.21 |
| Cyanide (Total) | $CN^-$(Total) | 0 | 4 | 7 | 28 | 0 | 0 |

**Table 2-8** Roodepoort waste rock total concentration analysis data

| Waste constituents | Abbreviation | R635 Total Concentration Threshold Values TCT0 mg/kg | TCT1 mg/kg | TCT2 mg/kg | Roodepoort Waste Rock Sample 1 mg/kg | Roodepoort Waste Rock Sample 2 mg/kg |
|---|---|---|---|---|---|---|
| **Metal Ions** | | | | | | |
| Arsenic | As | 5.8 | 500 | 2 000 | 20 | 42 |
| Boron | B | 150 | 15 000 | 60 000 | 6 | <4 |
| Barium | Ba | 62.5 | 6 250 | 25 000 | 4 | 4 |
| Cadmium | Cd | 7.5 | 260 | 1 040 | <2 | <2 |
| Cobalt | Co | 50 | 5 000 | 20 000 | <2 | <2 |
| Chromium (Total) | Cr(Total) | 46 000 | 800 000 | n.a | 30 | 58 |
| Chromium (VI) | Cr(VI) | 6.5 | 500 | 2 000 | <2 | <2 |
| Copper | Cu | 16.0 | 19 500 | 78 000 | 7 | 21 |
| Mercury | Hg | 0.93 | 160 | 640 | <1 | <1 |
| Manganese | Mn | 1 000 | 25 000 | 100 000 | 19 | 20 |
| Molybdenum | Mo | 40 | 1 000 | 4 000 | <2 | <2 |
| Nickel | Ni | 91 | 10 600 | 42 400 | 3 | 11 |
| Lead | Pb | 20 | 1 900 | 7 600 | <2 | <2 |
| Antimony | Sb | 10 | 75 | 300 | <2 | <2 |
| Selenium | Se | 10 | 50 | 200 | <2 | <2 |
| Vanadium | V | 150 | 2 680 | 10 720 | 4 | 14 |
| Zinc | Zn | 240.0 | 160 000 | 640 000 | 8 | 9 |
| **Inorganic Anions** | | | | | | |
| Fluoride | F | 100 | 10 000 | 40 000 | <10 | <10 |
| Cyanide (Total) | $CN^-$(Total) | 14 | 10 500 | 42 000 | 0 | 0 |

### *2.4.3 Waste classification results*

Based on the criteria in Section 7 of R635, the Roodepoort waste rock is classified as Type 3, which according to R636 requires a Type C engineered barrier system.

## 2.5 Rugby Club

### *2.5.1 Leachate analysis*

The leachate assessment data is shown in Table 3-1. The assessment indicates that none of the parameters analysed is leached in concentrations that exceed the regulatory values of R635 in the Waste Rock 2 sample. Arsenic leaches in concentrations exceeding the LCT0 value of R635.

### *2.5.2 Total concentration analysis*

The total concentration assessment data is shown in Table 3-2. The assessment indicates that arsenic concentrations in the Rugby Club waste rock samples 1 and 2 exceed the TCT0 value, but is less than the TCT1 value, of R635. Copper in Waste Rock sample 2 exceeds the TCT0 value of R635.

### 2.5.3 Waste classification results

Based on the criteria in Section 7 of R635, the Rugby Club waste rock is classified as Type 3, which according to R636 requires a Type C engineered barrier system.

# 3 CONCEPTUAL GEOCHEMICAL FRAMEWORK

A conceptual model is a simplified description in words and/or diagrammatical / schematic representation of the problem as seen by the analyst. It represents how we perceive and process the information of a specific system and forms the foundation of the numeric geochemical modelling. The conceptual model of the waste rock material is discussed in this section. A conceptual model for the West Wits waste rock material is shown in Figure 3-1.

The main water flux into and from the waste rock facility is driven by rainfall and evaporation. Some water may be introduced due to dumping of fresh, wet waste rock material onto the waste rock dump. Seepage occurs due to rainfall events as well as the dumping of wet waste rock material. The waste rock material may be associated with elevated nitrate concentrations due to blasting with ammonium nitrate-based explosives. However, this is not due to the waste rock material itself, as will be discussed below as well as in Section 5. It is due to process water, which may contain elevated concentrations of nitrate, together with the waste rock material.

The waste rock material is comprised of minerals. The minerals of which the waste rock consists, according to the XRD analysis, are quartz [$SiO_2$] (54.7 wt.%) and pyrophyllite [$Al_2Si_4O_{10}(OH)_2$] (43.7 wt.%) with minor amounts of muscovite [$KAl_2(AlSi_3)O_{10}(OH)_2$] (0.8 wt.%) and lizardite [$Mg_3Si_2O_5(OH)_4$] (0.8 wt.%). These minerals have the potential to slowly break down and form secondary mineral products.

**Table 3-1** Rugby Club waste rock leachate analysis data

| Inorganic Waste constituents | Abbreviation | R635 Leach Concentration Threshold Values LCT0 | LCT1 | LCT2 | LCT3 | Rugby Club Waste Rock Sample 1 | Rugby Club Waste Rock Sample 2 |
|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| **Metal Ions** | | | | | | | |
| Arsenic | As | 0.01 | 0.5 | 1 | 4 | 0.056 | <0.002 |
| Boron | B | 0.5 | 25 | 50 | 200 | <0.01 | <0.01 |
| Barium | Ba | 0.7 | 35 | 70 | 280 | <0.002 | <0.002 |
| Cadmium | Cd | 0.003 | 0.15 | 0.3 | 1.2 | <0.002 | <0.002 |
| Cobalt | Co | 0.5 | 25 | 50 | 200 | <0.002 | <0.002 |
| Chromium (Total) | Cr(Total) | 0.1 | 5 | 10 | 40 | <0.002 | <0.002 |
| Chromium (VI) | Cr(VI) | 0.05 | 2.5 | 5 | 20 | <0.002 | <0.002 |
| Copper | Cu | 2.0 | 100 | 200 | 800 | <0.002 | <0.002 |
| Mercury | Hg | 0.006 | 0.3 | 0.6 | 2.4 | <0.002 | <0.002 |
| Manganese | Mn | 0.5 | 25 | 50 | 200 | 0.005 | 0.006 |
| Molybdenum | Mo | 0.07 | 3.5 | 7 | 28 | <0.002 | <0.002 |
| Nickel | Ni | 0.07 | 3.5 | 7 | 28 | <0.002 | <0.002 |
| Lead | Pb | 0.01 | 0.5 | 1 | 4 | <0.002 | <0.002 |
| Antimony | Sb | 0.02 | 1.0 | 2 | 8 | <0.002 | <0.002 |
| Selenium | Se | 0.01 | 0.5 | 1 | 4 | <0.002 | <0.002 |
| Vanadium | V | 0.2 | 10 | 20 | 80 | 0.007 | <0.002 |
| Zinc | Zn | 5.0 | 250 | 500 | 2 000 | 0.003 | 0.004 |
| **Inorganic Anions** | | | | | | | |
| Total Dissolved Solids | TDS | 1 000 | 12 500 | 25 000 | 100 000 | 36 | 45 |
| Chloride | Cl | 300 | 15 000 | 30 000 | 120 000 | <5 | <5 |
| Sulphate | $SO_4$ | 250 | 12 500 | 25 000 | 100 000 | 4 | 6 |
| Nitrate as Nitrogen | $NO_3$-N | 11 | 550 | 1 100 | 4 400 | <0.2 | 0.6 |
| Fluoride | F | 2 | 75 | 150 | 600 | <0.1 | 0.21 |
| Cyanide (Total) | $CN^-$(Total) | 0 | 4 | 7 | 28 | 0 | 0 |

**Table 3-2** Rugby Club waste rock total concentration analysis data

| | | R635 Total Concentration Threshold Values | | | Rugby Club Waste Rock Sample 1 | Rugby Club Waste Rock Sample 2 |
|---|---|---|---|---|---|---|
| Waste constituents | Abbreviation | TCT0 | TCT1 | TCT2 | | |
| | | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| **Metal Ions** | | | | | | |
| Arsenic | As | 5.8 | 500 | 2 000 | 20 | 42 |
| Boron | B | 150 | 15 000 | 60 000 | 6 | <4 |
| Barium | Ba | 62.5 | 6 250 | 25 000 | 4 | 4 |
| Cadmium | Cd | 7.5 | 260 | 1 040 | <2 | <2 |
| Cobalt | Co | 50 | 5 000 | 20 000 | <2 | <2 |
| Chromium (Total) | Cr(Total) | 46 000 | 800 000 | n.a | 30 | 58 |
| Chromium (VI) | Cr(VI) | 6.5 | 500 | 2 000 | <2 | <2 |
| Copper | Cu | 16.0 | 19 500 | 78 000 | 7 | 21 |
| Mercury | Hg | 0.93 | 160 | 640 | <1 | <1 |
| Manganese | Mn | 1 000 | 25 000 | 100 000 | 19 | 20 |
| Molybdenum | Mo | 40 | 1 000 | 4 000 | <2 | <2 |
| Nickel | Ni | 91 | 10 600 | 42 400 | 3 | 11 |
| Lead | Pb | 20 | 1 900 | 7 600 | <2 | <2 |
| Antimony | Sb | 10 | 75 | 300 | <2 | <2 |
| Selenium | Se | 10 | 50 | 200 | <2 | <2 |
| Vanadium | V | 150 | 2 680 | 10 720 | 4 | 14 |
| Zinc | Zn | 240.0 | 160 000 | 640 000 | 8 | 9 |
| **Inorganic Anions** | | | | | | |
| Fluoride | F | 100 | 10 000 | 40 000 | <10 | <10 |
| Cyanide (Total) | $CN^-$(Total) | 14 | 10 500 | 42 000 | 0 | 0 |

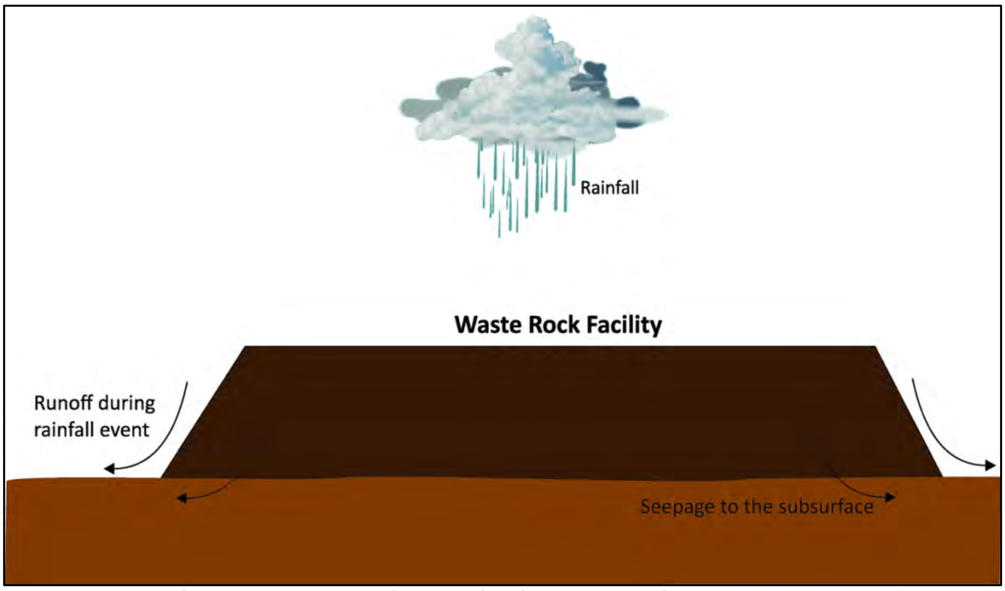


**Figure 3-1** Conceptual model of the 11 Shaft waste rock facility

The rate at which these minerals break down are important from an environmental point of view as some minerals have the potential to release harmful substances into the environment. However, some minerals have the ability to remove harmful substances through the process of adsorption. The geochemical modelling is designed to quantify the balance of these processes. The XRD as well as the sulphur speciation analysis indicates that there are no sulphide minerals associated with the waste rock material. None of the minerals listed above are reactive at sufficient rates at the ambient conditions of the mining environment to cause the release of harmful substances into the environment. Therefore, the seepage from the waste rock is not likely to contain any elevated concentrations of potentially hazardous constituents. In addition, the minerals pyrophyllite is a clay mineral has significant adsorption capacity for potential contaminants.

The acid base accounting and net acid generation tests confirm the above by indicating that the waste rock is not likely to generate acid mine drainage (AMD) conditions due to its insignificant acid generation potential.

This conceptual understanding is evaluated by developing a numeric geochemical model of the waste rock which takes important geochemical processes, such as mineral reaction rates, solubility of minerals and the formation of secondary minerals and their influence in the waste rock environment, into account.

# 4 NUMERIC GEOCHEMICAL MODELS

The laboratory data as described in Section 1.2 was used as input to the numeric geochemical models. The detailed model parameterisation is described in Appendix B. The model was developed with three main data inputs. The first is the gas phase, as represented by the Earth's atmosphere. The oxygen content was kept constant as the waste rock facility was modelled as single entity.

The second input is the solution, which is rainwater. Using this assumption provides information on the behaviour of specifically the material being considered. The third input is the mineral mass, of which the primary minerals are derived from the laboratory analyses.

The results presented in the table in the sections below should be viewed from the perspective of risk quantification. In other words, it is unlikely that the model concentrations and parameter values of the eventual leachate for the facilities will exactly match those of reality; they do provide information on the likelihood of specific risks, e.g. the formation of acid mine drainage conditions and/or the presence of elevated concentrations of metal(loid)s.

## 4.1 Waste rock model results

As the model results for the waste rock of the different mine sites are similar, the general results for the leachate from the waste rock material are shown in Table 4-1 and for the predicted secondary minerals in Table 4-2. The leachate results in Table 4-1 indicate that the material of which the waste rock consists is unreactive. This is due to the fact that the waste rock contains minerals which are stable at the Earth’s surface. Iron sulphides, which have the potential to produce AMD, are absent from the waste rock material.

**Table 4-1** Waste rock leachate model results

| Parameter | Abbreviation | *Units* | Value |
|---|---|---|---|
| **pH** | pH | *pH units* | 7.02 |
| **Total Dissolved Solids** | TDS | *mg/ℓ* | 19.8 |
| **Total Alkalinity** | T Alk | *mg CaCO3/ℓ* | < 10 |
| **Sodium** | Na | *mg/ℓ* | < 1 |
| **Calcium** | Ca | *mg/ℓ* | < 1 |
| **Magnesium** | Mg | *mg/ℓ* | < 1 |
| **Potassium** | K | *mg/ℓ* | 13 |
| **Aluminium** | Al | *mg/ℓ* | < 0.01 |
| **Arsenic** | As | *mg/ℓ* | < 0.01 |
| **Copper** | Cu | *mg/ℓ* | < 0.01 |
| **Iron** | Fe | *mg/ℓ* | < 0.01 |
| **Nitrate** | $NO_3$ | *mg/ℓ* | 0.4 |
| **Sulphate** | $SO_4$ | *mg/ℓ* | 6.4 |

**Table 4-2** Model results for predicted secondary minerals

| Secondary Minerals present | Ideal mineral formula |
|---|---|
| **Goethite** | FeOOH |
| **Kaolinite** | $Al_2Si_2O_5(OH)_4$ |
| **Nontronite** | $(Ca_{0.5}Na)_{0.3}Fe_2(Si,Al)_4O_{10}(OH)_2.nH_2O$ |

Therefore, the pH of the leachate is neutral (7.05). The high stability of the minerals is the reason for the low total dissolved solids of 6.5 mg/ℓ. The nitrate concentration of 0.4 is due to the small amounts of nitrogen in the atmosphere that are dissolved in rain water and can be oxidised to nitrate. The model indicates that nitrate does not occur in any of the minerals of which the waste rock is comprised and that the waste rock material therefore cannot produce a leachate with elevated nitrate concentrations from the waste rock material itself. The concentration of nitrate in the leachate is therefore low and the little that occurs in the waste rock leachate is due to the presence of nitrogen in the atmosphere. It is however possible that nitrate may occur in the waste rock material as it is transported from the mining area to the waste rock facility after blasting, due to the use of ammonium nitrate-based explosives. This could not be taken into account in the modelling but must be considered a potential risk to groundwater and surface water in the operational phase of the mining project. As soon as mining ceases, the nitrate addition stops.

The small amounts of secondary minerals predicted by the model to form (Table 4-2) are iron and aluminium oxy-hydroxides as well as clay minerals. These minerals are all stable under the waste rock conditions and additionally have the capacity to remove any potential contaminants, such as copper, through the process of adsorption. This is another reason that the concentrations of leachable contaminants are shown in the leach test to be negligible.

# 5 IMPLICATIONS FOR ENVIRONMENTAL IMPACTS AND MITIGATION

## 5.1 Methodology used in determining the significance of environmental impacts

The method used for the assessment of environmental issues is set out in Table5-1. This assessment methodology enables the assessment of environmental issues including: cumulative impacts, the severity of impacts (including the nature of impacts and the degree to which impacts may cause irreplaceable loss of resources), the extent of the impacts, the duration and reversibility of impacts, the probability of the impact occurring, and the degree to which the impacts can be mitigated.

**Table5-1 Impact assessment methodology**

*Note: Part A provides the definition for determining impact consequence (combining intensity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.*

| PART A: DEFINITION AND CRITERIA* | | |
|---|---|---|
| **Definition of SIGNIFICANCE** | | **Significance = consequence x probability** |
| **Definition of CONSEQUENCE** | | **Consequence is a function of severity, spatial extent and duration** |
| **Criteria for ranking of the SEVERITY of environmental impacts** | **H** | Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. |
| | **M** | Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. |
| | **L** | Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. |
| | **L+** | Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. |
| | **M+** | Moderate improvement. Will be within or better than the recommended level. No observed reaction. |
| | **H+** | Substantial improvement. Will be within or better than the recommended level. Favourable publicity. |
| **Criteria for ranking the DURATION of impacts** | **L** | Quickly reversible. Less than the project life. Short term |
| | **M** | Reversible over time. Life of the project. Medium term |
| | **H** | Permanent. Beyond closure. Long term. |
| **Criteria for ranking the SPATIAL SCALE of impacts** | **L** | Localised - Within the site boundary. |
| | **M** | Fairly widespread – Beyond the site boundary. Local |
| | **H** | Widespread – Far beyond site boundary. Regional/ national |

| PART B: DETERMINING CONSEQUENCE | | | | | |
|---|---|---|---|---|---|
| **SEVERITY = L** | | | | | |
| **DURATION** | Long term | **H** | **Medium** | **Medium** | **Medium** |

| | | | | | |
|---|---|---|---|---|---|
| | Medium term | M | Low | Low | Medium |
| | Short term | L | Low | Low | Medium |
| **SEVERITY = M** | | | | | |
| **DURATION** | Long term | H | Medium | High | High |
| | Medium term | M | Medium | Medium | High |
| | Short term | L | Low | Medium | Medium |
| **SEVERITY = H** | | | | | |
| **DURATION** | Long term | H | High | High | High |
| | Medium term | M | Medium | Medium | High |
| | Short term | L | Medium | Medium | High |
| | | | **L** | **M** | **H** |
| | | | Localised<br>Within site boundary<br>Site | Fairly widespread<br>Beyond site boundary<br>Local | Widespread<br>Far beyond site boundary<br>Regional/ national |
| | | | **SPATIAL SCALE** | | |

| **PART C: DETERMINING SIGNIFICANCE** | | | | | |
|---|---|---|---|---|---|
| **PROBABILITY**<br>**(of exposure to impacts)** | Definite/ Continuous | H | Medium | Medium | High |
| | Possible/ frequent | M | Medium | Medium | High |
| | Unlikely/ seldom | L | Low | Low | Medium |
| | | | **L** | **M** | **H** |
| | | | **CONSEQUENCE** | | |

| **PART D: INTERPRETATION OF SIGNIFICANCE** | |
|---|---|
| **Significance** | **Decision guideline** |
| High | It would influence the decision regardless of any possible mitigation. |
| Medium | It should have an influence on the decision unless it is mitigated. |
| Low | It will not have an influence on the decision. |

***H = high, M= medium and L= low and + denotes a positive impact.**

## 5.2 Identified environmental impacts

### *5.2.1 Acid Mine Drainage*

The acid base accounting and geochemical modelling have indicated that due to the absence of iron sulphide minerals the risk of the development of AMD conditions in the waste rock environment is negligible.

### *5.2.2 Leaching of metal(loid) contaminants*

The leach test indicated that all by three potential contaminants are below detection in the waste rock leachate and the three that are above detection have concentrations significantly below the regulatory values. The geochemical model, which was developed to evaluate the leach test, also shows that the risk of leaching of contaminants, especially the metalloid arsenic, from the waste rock is negligible. This is also due to the absence of iron sulphide as well as the high stability of the minerals comprising the waste rock at the mining conditions.

#### *5.2.3 Mitigation*

Due to the negligible risk of the formation of AMD conditions as well as the negligible risk of the leaching of contaminants from the waste rock material, no mitigation measures are required for the waste rock material.

The results of the assessment are shown in Table 5-2. The results indicate that the significance of both potential impacts rate as *Low*. The cumulative impacts of the impacts rate as *Low*. This is predominantly because of the fact that the development of AMD conditions as well as the leaching of contaminants from the waste rock is unlikely.

**Table 5-2** Environmental impact assessment matrix for geochemical impacts

| Potential Impact | Activity | Alternative | Project Phases | Consequence | | | Probability | Significance | Degree to which impact can: | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Severity | Duration | Spatial Scale | | | be reversed | cause irreplaceable loss of resource | be avoided/ Managed/ Mitigated |
| Mass migration from waste rock dumps: AMD formation | Disposal of waste rock onto the waste rock facility and resultant formation of acid mine drainage conditions | All | O,D | M | L | L | M | L | Fully | Unlikely | Managed / Mitigated |
| Mass migration from waste rock dumps: Metal(loid)s, especially arsenic from the material | Disposal of waste rock onto the waste rock facility and resultant leaching of metal(loid)s, especially arsenic from the material. | All | O,D | M | L | L | M | L | Fully | Unlikely | Managed / Mitigated |

# 6 CONCLUSIONS

The following conclusions follow from the geochemical assessment:

- The risk of the development of acid mine drainage conditions in the waste rock facility is negligible.
- The risk of the leaching of potential metal(loid) contaminants from the waste rock material is negligible.
- There is some risk that nitrate concentrations could impact the on-site groundwater due to process water being co-disposed of together with the waste rock material on the waste rock facility. I.e. the potentially elevated nitrate concentrations are not due to the waste rock material itself. This risk is an operational issue as the nitrate source, blasting using ammonium nitrate-based explosives, can easily be contained by extraction boreholes if necessary. The nitrate issue is not considered a post-closure problem, as the source of the nitrates cease as soon as blasting ceases.

# 7 RECOMMENDATIONS

The following recommendations are made following the study:

- The waste rock material is classified as Type 3 according to NEMWA Regulation 635. It is recommended, based on the results of this assessment, that the waste material class be reduced to Class 4.

# 8 APPENDIX A – MODEL PARAMETERISATION

The waste rock was modelled by developing a single model. This is due to the greater degree of oxygen ingress into a waste dump, due to its courser size and also greater hydraulic conductivity, which allows more oxygen-rich water to percolate through the waste rock facility.

## 8.1 Parameterisation

### *8.1.1 Gas phase*

The gas phase is the Earth's atmosphere containing mostly nitrogen (79%), oxygen (21%) and carbon dioxide (400 ppm). The minor constituents of the Earth's atmosphere were not added as they would not influence the geochemical processes with in waste rock material in any way. The dump is assumed to be in equilibrium with the Earth's atmosphere, which is a conservative assumption.

### *8.1.2 Liquid phase*

The liquid is assumed to be rainwater in equilibrium with the Earth's atmosphere. No dissolved substances other than the equilibration with the Earth's atmosphere are added to the rainwater, as compared to the dissolved solid load of the waste rock leachate, the concentrations of dissolved constituents in rainwater are negligible.

### *8.1.3 Solid phase*

Waste rock is defined as unmineralised rock which is excavated to gain access to the ore. The mineral composition as shown in the XRD analysis (Appendix B) were input into the model as the solid phases. The dissolution of the minerals was controlled by the software default rate equation.

The metalloid, arsenic, was added to the model to evaluate its solubility and mobility in the waste rock environment. The total analysis (Appendix B) concentration was used as input to the model.

## 8.2 Model assumptions

### *8.2.1 Water-rock ratio*

A static water-rock ratio of 1:3 is assumed, implying a porosity of ~30%. Although this ratio can be expected to fluctuate during the year depending on the seasons and thus precipitation, it is not expected to have any significant influence on the model results. This is due to the high stability of the minerals of which the waste rock is comprised.

### *8.2.2 Mineral reaction rates*

The default rate equation was used to control the rate at which the waste rock minerals weather. The rate equation requires a rate constant, which is sourced from literature. However, the literature rate constants are conservative, in that minerals always react slower in nature than in the laboratory, where these rate constants are determined. Therefore, this assumption is justified as the minerals can only react faster in the real waste rock environment.

## 8.3 Model sensitivities

A model sensitivity analysis entails the variation of specific model input parameters to determine whether the model is sensitive to those parameters. The following sensitivities, which are shown to be potential sources of uncertainty in the models, were evaluated:

1. Mineral rate constants
2. Mineral surface areas

However, even though the model showed variances in output values with regards to changes in the above-mentioned parameters, the variations were not of environmental risk significance.

# 9 APPENDIX B – LABORATORY CERTIFICATES

# West Wits MLI (Pty) Ltd
# Hydrogeological Specialist Investigation for the Proposed West Wits Mining Project

May 2019 (version 1.1)
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Prepared for:
West Wits MLI (Pty) Ltd

Compiled by:
Stephan Meyer
Lucas Smith

Noa Agencies (Pty) Ltd
22 Bergview Estate
Zwavelpoort
Pretoria
Tel: (+27) 72 570 7186
Email: stephan@noa8.co.za

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| Marline Medallie | SLR Consulting (Pty) Ltd |
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| 04 | | | | | |

## DISCLAIMER

# LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| AMD | Acid Mine Drainage |
| BH | Borehole |
| BPG | Best Practice Guideline |
| CoC | Chemicals of Concern |
| DRD | Durban Roodepoort Deep |
| DWAF | Department of Water Affairs and Forestry (now DWS) |
| DWS | Department of Water and Sanitation |
| EC | Electrical Conductivity |
| g | grams |
| g/t | grams per ton |
| GPS | Global Positioning System |
| ha | Hectares |
| kg | Kilograms |
| km | kilometre |
| L/s | Litre per second |
| LOM | Life of Mine |
| l/day | litres per day |
| m | metre |
| $m^3$ | cubic metre |
| $m^3$/day | cubic metre per day |
| MAE | Mean Annual Evaporation |
| m amsl | metres above mean sea level |
| MAP | Mean Annual Precipitation |
| m bgl | metres below ground level |
| mg/ℓ | milligrams per litre |
| ml | millilitre |
| mm | millimetre |
| mm/a | millimetre per annum |
| Moz | Million ounces |
| MR | Mining Right |
| MRA | Mining Right Application |
| mS/m | milli Siemens per metre |
| MWP | Mining Works Program |
| NGA | National Groundwater Archive |
| NWA | National Water Act |
| oz | Ounces |
| PCD | Pollution Control Dam |

| | |
|---|---|
| Ptn | Portion |
| PR | Prospecting Right |
| SANAS | South African National Accreditation System |
| SANS | South African National Standards |
| SWL | Static Water Level |
| S | Storage coefficient (-) |
| TDS | Total Dissolved Solids |
| T | Transmissivity |
| tpm | tonnes per month |
| TSF | Tailings Storage Facility |
| WQO | Water Quality Objectives |
| WRC | Water Research Commission |
| WRD | Waste Rock Dump |
| WMA | Water Management Area |

## Executive Summary

The West Wits project area is located approximately 15 kilometres (km) west of Johannesburg. Hydrogeological field investigations were performed to assess the local aquifer characteristics. The detailed Scope of Work followed included:

- Data evaluation and hydrocensus user survey
  - Desk study and review of existing groundwater baseline information and groundwater monitoring data.
  - Hydrocensus user survey to visit existing surface and groundwater uses, borehole locations and depths, regional water levels, abstraction volumes and environmental receptors.
  - Interpretation of hydrocensus and hydro chemical data and trend analysis.
- Geochemical model and analyses
  - Sampling of 3 waste samples and submitted to an accredited lab for acid leach, ABA and composition analyses
  - Detailed geochemical assessment of the sample results to obtain potential leachate values and long term simulated effects on immediate environment.
- Construct detailed numerical groundwater flow model: Dewatering and contaminant transport modelling
  - Construct the conceptual groundwater flow model with the various proposed activities and possible impacts
  - Construct a regional 3D numerical groundwater flow dewatering model
  - Construct the contaminant transport model
  - Cumulative water impact – quality and quantity
  - Model calibration
  - The model will be used to update and determine the impact of management decisions on:
    - Groundwater flow directions and velocities.
    - Mine dewatering rates and water supply with the radius of influence.
    - Mitigation measures
    - Contaminant transport from mine residue facilities.
- Geohydrological assessment, reporting and cumulative impact assessments
- Compilation of a detailed geohydrological and hydrological specialist report addressing the following:
  - Conceptual dewatering volumes with mine planning
  - Mitigation and management measures.
  - Groundwater management
- Cumulative impact assessments: Detailed impact ratings of proposed activities on measured baselines, taking into consideration current activities within the catchment

The following are the key outcomes:

- The Witwatersrand and Ventersdorp Formations (local aquifers) are classified as least vulnerable based on the aquifer vulnerability map published by the Department of Water and Sanitation (DWS) in July 2013.
- Based on the aquifer classification map published by the Department of Water and Sanitations (DWS) in August 2012 the aquifer classification system defines the

Witwatersrand and Ventersdorp Formations as minor aquifers.

- Based on the susceptibility classification the Witwatersrand and Ventersdorp Formations have a low susceptibility to contamination.

A project wide hydrocensus was completed in 2018 during which 13 boreholes were identified, of which only four water levels could be measured. The number of measurable groundwater points raised a concern with regards to a gap in available groundwater levels and quality in or close to the various open pits i.e. Kimberley Reef East, 11 Shaft, Rugby Club, Mona Lisa and Roodepoort. Additional work (drilling and aquifer/water quality testing of monitoring boreholes at each site) is proposed before mining commences. The groundwater flow model should also be updated once this data becomes available. An additional 123 properties were assessed; however, the land owners indicated no boreholes are located on these properties.

Neighbouring mining monitoring data was not available at the time of reporting on the proposed mining development. Samples were taken at six boreholes and four surface water points. The samples indicated historical and present influences rendering the water unfit for human consumption. This indicated a high present impact on the baseline groundwater and surface water environments. Based on the South African National Standard (SANS241) drinking water guideline the sampled groundwater and surface water is not fit for human consumption (unless treated).

The numerical groundwater flow model was constructed based on the available data. The groundwater flow model should be viewed as conceptual and qualified rather than calibrated due to the low density of data points in and around the proposed open pit areas.

- Little to no mine dewatering is foreseen due to the shallow open pits proposed (i.e. <30m deep). Minor seepage and dewatering could be required during the wet season and runoff from the Waste Rock Dump (WRD) and local catchment.
- The sampling of the waste rock was conducted by Shango Solutions (Pty) Ltd. A detailed memo compiled by Prof S A. de Waal is available of the site and sample selection for analyses: Memo title - Note on the lateral lithological continuity of the Upper Witwatersrand Supergroup rocks
- The geochemical nature of the waste rock was assessed and reported on in detail in Geochemical Assessment for the proposed West Wits Mining Project, R N Hansen. 02 May 2019. The following key conclusions from the report was taken into account with the mass transport simulations for the Waste Rock Dump:
    - Acid Mine Drainage: The acid base accounting and geochemical modelling have indicated that due to the absence of iron sulphide minerals the risk of the development of AMD conditions in the waste rock environment is negligible.
    - Leaching of metal(loid) contaminants: The leach test indicated that all by three potential contaminants are below detection in the waste rock leachate and the three that are above detection have concentrations significantly below the regulatory values. The geochemical model, which was developed to evaluate the leach test, also shows that the risk of leaching of contaminants, especially the metalloid arsenic, from the waste rock is negligible. This is also due to the absence of iron sulphide as well as the

high stability of the minerals comprising the waste rock at the mining conditions.
    - Based on this a Class D barrier system (stripping topsoil and base preparation) was recommended by the geochemistry specialist. This has been taking into account in this study.
    - Mitigation: Due to the negligible risk of the formation of AMD conditions as well as the negligible risk of the leaching of contaminants from the waste rock material, no mitigation measures are required for the waste rock material.
- For the mass transport simulations, due to the absence of any possible leachate, a conceptual mass transport simulation was conducted for management purposes and to assist the applicant in monitoring the possible influence of the WRD during operations and the backfilled open pit during post operations. To simulate the movement of groundwater based on the physical characteristics of the waste rock material, a conceptual background value of 5% (i.e. 5 mg/L) was assigned to the host rock, and a potential leachate from the WRD of 100% (i.e. 100 mg/L ~ 100% of a possible certain mass originating from the WRD and open pit post closure representing the worst-case scenario). This simulation intends to assist the applicant in continuing the monitoring protocol suggested. Please note that the mass migration simulation is for management purposes and the chosen parameters (5% for background and 100% for source) simulate worst case scenario i.e. although the source term would remain 100%, the background value may alter to 10, 20 or 50%, influencing the mass migration potential.

The possible impacts and mitigation measures were assessed, and key findings are as follows:

- Mine dewatering cannot be mitigated as this is a potential result of excavation and intersecting the groundwater table. Inflows could be generated which should be managed. Limiting the volume of water reporting to the open pit will limit the volume of water requiring treatment before disposing.
- Zero to little influence on the local groundwater regime was simulated due to the shallow pit and deep groundwater levels:
    - Mona Lisa Open Pit: Lowering of groundwater levels were predicted in a limited extent
    - Roodepoort Open Pit: No impact on groundwater levels predicted
    - Rugby Club Open Pit: No impact on groundwater levels predicted
    - 11 Shaft Open Pit: Lowering of groundwater levels were predicted in a limited extent
    - Kimberley East Reef Open Pit: Lowering of groundwater levels were predicted in a limited extent
    - Underground Mining: Little to no impact on the groundwater levels due to underground mining.
- The associated simulated/predicted impacts are medium to low and should there be a limited impact, it can be fully reversed.
- Mass migration from the temporary WRD's associated with each open pit is limited and the material will be used to concurrently backfill the open pit. No blasting will take place during open pit mining; hence no nitrates are introduced to the system. The geochemical assessment also indicted no potential leachates from the WRD

material. Hence from the onset, the potential impact is low.

- The potential of the WRDs to leach minerals into the receiving environment and negatively influencing the groundwater and surface water quality. The simulations were done for each open pit WRD:
    - Mona Lisa Open Pit: Minimum impact predicted on tributary located to the south of the WRD
    - Roodepoort Open Pit: No impact predicted on any recorded sensitive receptor
    - Rugby Club Open Pit: No impact predicted on any recorded sensitive receptor
    - 11 Shaft Open Pit: Minimum impact predicted on tributary located to the south of the WRD
    - Kimberley East Reef Open Pit: No impact predicted on any recorded sensitive receptor.

Monitoring boreholes should be implemented as follows:

- In the backfilled open pit areas post closure
- Mona Lisa Open Pit: Between the WRD and the tributary to the south and between the open pit and the Klip River to the west.
- Roodepoort Open Pit: South of the western WRD
- Rugby Club Open Pit: North of the open pit between the open pit and the school fields
- 11 Shaft Open Pit: North of the open pit and between the WRD and the tributary to the south
- Kimberley East Reef Open Pit: North of the eastern open pit.

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# 1 Introduction

Mines across the mining right application area for the West Wits Mining Project (Durban Roodepoort Deep and Rand Leases) closed prematurely during 2001. Due to the premature closure of the mines, significant mineable resources remain within the proposed West Wits Project area. West Wits' focus over the last years was the establishment of code compliant and Exploration Target resources employing relevant historical data, in addition to exploration activities.

Historically, 11 auriferous conglomerate horizons, locally referred to as reefs, have been mined across the proposed West Wits Project area. The mining targets are the auriferous conglomerates of the Central Rand Group, Witwatersrand Supergroup. These are the North Reef, Main Reef, Main Reef Leader, South Reef, Livingstone Reef, Bird Reef, Monarch Reefs, Kimberley Reefs, and Ventersdorp Contact Reef. The latter is situated at the base of the Ventersdorp Supergroup within the Venterspost Conglomerate Formation. The Central Rand Group is subdivided into the older Johannesburg (containing the Main, Randfontein, Luipaardsvlei, Krugersdorp, and Booysens formations) and the younger Turffontein (containing the Kimberley, Elsburg and Mondeor formations) subgroups.

The gold tends to be enriched in discrete areas, termed payshoots. Syn-depositional tectonic activity was present throughout the deposition of the Central Rand Group, Witwatersrand Supergroup, but was especially pronounced during the deposition of the Kimberley reefs. This resulted in a warped palaeo-surface, comprised of syn- and antiforms.

Between 1888 and 2001 the mines across the proposed West Wits Project area produced 1,270,870 kg of gold (40,857,467 ounces), at an average grade of 4.92 g/t.

Depth of the mineralisation extends from surface to 3 000 metres (m) beneath surface. The proposed West Wits project area is located approximately 15 kilometres (km) west of Johannesburg. The mine will be located on various portions of the farms Roodepoort 236 IQ, Roodepoort 237 IQ, Witpootjie 245 IQ, Vlakfontein 238 IQ, Vogelstruisfontein 231 IQ and Volgelstruisfontein 233 IQ.

Portion 408 of the farm Roodepoort 237 IQ and a section of the access/haul road will be located on a portion of Portion 407 of the farm Roodepoort 237 IQ.

## 1.1 Groundwater Study Objectives

The groundwater impact assessment has the following objectives:

1. Define the current groundwater characteristics for the Roodepoort, Rugby Club, 11 Shaft, Kimberley East and Mona Lisa open pit mining areas and surroundings (the Project area);
2. The project includes the surface infrastructure complexes associated with the two proposed underground mining operations i.e. Kimberley Reef East and Bird Reef Central.
3. Define potential receptors in the Project area;
4. Define the aquifers underlying the Project area, including groundwater table depth, groundwater quality, and flow characteristics;

5. Develop a numerical model to define groundwater related impacts and groundwater inflow into the open pits and underground mine workings;
6. Define the zone of influence (if any) that will be created by mine dewatering, plus the extent of possible contamination originating from the proposed mining areas and mine infrastructure;
7. Assess whether decant will occur during the operational phase or post closure; and
8. Recommend a groundwater monitoring network that will enhance the current monitoring of groundwater quality and level changes; during the operational and closure phases.

## 1.2 Scope of Work

### 1.2.1 Phase A: Data evaluation and hydrocensus user survey

1. Desk study and review of existing groundwater baseline information and groundwater monitoring data.
2. Hydrocensus user survey to visit existing surface and groundwater uses, borehole locations and depths, regional water levels, abstraction volumes and environmental receptors.
3. Interpretation of hydrocensus and hydro chemical data and trend analysis.

### 1.2.2 Phase B: Geochemical model and analyses

1. Sampling of 3 waste samples and submitted to an accredited lab for acid leach, ABA and composition analyses
2. Detailed geochemical assessment of the sample results to obtain potential leachate values and long term simulated effects on immediate environment.

### 1.2.3 Phase C: Construct detailed numerical groundwater flow model: Dewatering and contaminant transport modelling

1. Construct the conceptual groundwater flow model with the various proposed activities and possible impacts
2. Construct a regional 3D numerical groundwater flow dewatering model
3. Construct the contaminant transport model
    a. Cumulative water impact – quality and quantity
4. Model calibration
5. The model will be used to update and determine the impact of management decisions on:
    a. Groundwater flow directions and velocities.
    b. Mine dewatering rates and water supply with the radius of influence.
    c. Mitigation measures
    d. Post-closure mine flooding and decanting.
    e. Contaminant transport from mine residue facilities.
6. Hydropedology study: The numerical flow model will be used to assess the impact

and flow reduction on various surface features (pans, depressions, wetlands etc.)

### 1.2.4 Phase D: Geohydrological assessment, reporting and cumulative impact assessments

1. Compilation of a detailed geohydrological and hydrological specialist report addressing the following:
    a. Conceptual dewatering design with mine planning
    b. Mitigation and management measures.
    c. Groundwater management
2. Cumulative impact assessments: Detailed impact ratings of proposed activities on measured baselines, taking into consideration current activities within the catchment

## 1.3 Compliance Framework

This groundwater impact assessment was undertaken to South African Best Practice Guidelines, defined by the Department of Water and Sanitation (DWS). A groundwater numerical flow and transport model supports the groundwater impact assessment; defining potential groundwater quality and quantity impacts; including impacts on the local groundwater users, communities and surface water resources.

The water quality assessment is based on South African National Standard (SANS) 241-1:2015, Drinking Water and Klip River Water Quality Objectives standards.

| No. | Requirement | Section in report |
|---|---|---|
| a) | Details of - | |
| (i) | The specialist who prepared the report | 18 Appendix C: Specialist CV |
| (ii) | The expertise of that specialist to compile a specialist report including a curriculum vitae | 18 Appendix C: Specialist CV |
| b) | A declaration that the specialist is independent | 1.5 Declaration of Independence |
| c) | An indication of the scope of, and the purpose for which, the report was prepared | 1.2 Scope of Work |
| cA) | An indication of the quality and age of base data used for the specialist report | 3Literature Review |
| cB) | A description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change | 6.2 Hydrocensus - 6.4 Groundwater Quality |
| d) | The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment | 6.2 Hydrocensus - 6.4 Groundwater Quality |
| e) | A description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used | |
| f) | Details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives | 10 **Predictive modelling** |
| g) | An identification of any areas to be avoided, including buffers | 10 **Predictive modelling** |
| h) | A map superimposing the activity including the associated structure and infrastructure on the environmental sensitivities of | 10 **Predictive modelling** |

| No. | Requirement | Section in report |
|---|---|---|
| | the site including areas to be avoided, including buffers | |
| i) | A description of any assumption made and any uncertainties or gaps in knowledge | 4 **Limitations and Assumptions**9.3.2 **Assumptions and limitations** |
| j) | A description the findings and potential implication\s of such findings on the impact of the proposed activity, including identified alternatives on the environment or activities | 10 **Predictive modelling** |
| k) | Any mitigation measures for inclusion in the EMPr | 11 **Environmental Impact Matrix** |
| l) | Any conditions for inclusion in the environmental authorisation | |
| m) | Any monitoring requirements for inclusion in the EMPr or environmental authorisation | 14 Monitoring Program |
| n) | A reasoned opinion - | |
| (i) | As to whether the proposed activity, activities or portions thereof should be authorised | |
| (iA) | Regarding the acceptability of the proposed activity or activities | |
| (ii) | If the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan | |
| o) | A description of any consultation process that was undertaken during the course of preparing the specialist report | |
| p) | A summary and copies of any comments received during any consultation process and where applicable all responses thereto; and | |
| q) | Any other information requested by the competent authority | |

### 1.4 Groundwater Assessment Team

The following hydrogeologists are involved in the West Wits groundwater assessment:

1. Stephan Meyer (BSc Hon. Geohydrology) Pr.Sci.Nat:
    a. Project Hydrogeologist.
    b. Data Analysis, Numerical Modelling, Reporting.
2. Lucas Smith (MSc Geohydrology) Pr.Sci.Nat:
    a. Data analysis and reporting.

### 1.5 Declaration of Independence

I, Willem Johannes (Stephan) Meyer, representing Noa Agencies (Pty) Ltd., hereby deciares that I am an independent consultant appointed to provide specialist input for the Mining Right Application (MRA). I confirm that I have no personal financial interest in the project other that n remuneration for the work associated with the MRA, and neither I or Noa Agencies (Pty) Ltd. will benefit in any other way from the outcomes of this study. I further declare that opinions expressed in this report have been formulated in an objective manner without interference from any third party.

## 2 Project Summary

West Wits has applied for a mining right in terms of the Mineral and Petroleum Resources Development Act (MPRDA) (No. 28 of 2002). Consent in terms of Section 11(2) of the MPRDA to cede a renewed prospecting right MPT No. 29/2016 from Mintails SA Soweto Cluster (Proprietary) Limited to West Wits was granted by the Department of Mineral

Resources (DMR) in 2018.

The open pit mining schedule stretches over a period of three years, with the infrastructure complexes for the underground mining constructed during year three and four. Underground mining will commence in year four and steady state production will be achieved during year five. The current simulated Life of Mine (but not limited to) for Kimberley Reef East and Bird Reef Central are 20 and 10 years respectively. The mining duration and detail (production, depth of mining, ore reserves and mine duration) for each individual open pit and underground mine is provided in Table 2-1.

Table 2-1 Mining Schedule (SLR, 2019)

| **Features** | | | **Details** | | | | |
|---|---|---|---|---|---|---|---|
| Target commodities | | | Gold, uranium and silver | | | | |
| Mineable resource | | | ~ 9 000 000 tonnes | | | | |
| **Opencast mining** | | | | | | | |
| Open pits | | | **Rugby Club** | **Roodepoort** | **11 Shaft** | **Mona Lisa** | **Kimberley East** |
| Location | | | See **Figure 2-1** | See **Figure 2-2** | See **Figure 2-1** | See **Figure 2-2** | See **Figure 2-1** |
| Coordinates | A | Longitude | 27° 53' 38.62"E | 27° 50' 57.47"E | 27° 53' 38.32"E | 27° 50' 17.66"E | 27° 53' 50.18"E |
| | | Latitude | 26° 10' 52.28"S | 26° 9' 54.74"S | 26° 11' 21.58"S | 26° 10' 35.60"S | 26° 12' 2.05"S |
| | B | Longitude | 27° 53' 44.62"E | 27° 50' 57.60"E | 27° 54' 1.52"E | 27° 50' 49.79"E | 27° 53' 49.87"E |
| | | Latitude | 26° 10' 53.89"S | 26° 9' 55.88"S | 26° 11' 28.05"S | 26° 10' 35.04"S | 26° 12' 3.15"S |
| | C | Longitude | 27° 53' 39.04"E | 27° 52' 3.02"E | 27° 54' 1.90"E | 27° 50' 49.23"E | 27° 54' 9.92"E |
| | | Latitude | 26° 10' 52.70"S | 26° 9' 55.00"S | 26° 11' 26.12"S | 26° 10' 32.82"S | 26° 12' 10.78"S |
| | D | Longitude | 27° 53' 39.04"E | 27° 52' 3.62"E | 27° 53' 38.93"E | 27° 50' 18.28"E | 27° 54' 10.58"E |
| | | Latitude | 26° 10' 51.05"S | 26° 9' 53.88"S | 26° 11' 19.64"S | 26° 10' 33.40"S | 26° 12' 9.91"S |
| Mining sequence | | | 1 | 2 | 3 | 4 | 5 |
| Mining direction | | | East to West | West to East | East to West | West to East | West to East |
| Size of mining area | | | ~ 2.6 ha | ~ 26.5 ha | ~ 15 ha | ~ 20 ha | ~ 9.2 ha |
| Mining rate (per month) | | | 15 000 tonnes | 15 000 tonnes | 15 000 tonnes | 15 000 tonnes | 15 000 tonnes |
| Pit depth | | | 7 to 10 m | 7 to 10 m | 20 to 30 m | 20 to 30 m | 20 to 30 m |
| Mineable resource (tonnes) | | | 30 212 | 179 290 | 117 631 | 34 351 | 62 917 |
| Mining duration (including concurrent rehabilitation, season dependent) | | | ~ 6 months | ~ 6 months | ~ 6 months | ~ 3 months | ~ 5 months |

| | | | | | |
|---|---|---|---|---|---|
| Final rehabilitation duration | ~ 3 months | ~ 2 months | ~ 2 months | ~ 2 months | ~ 2 months |
| Temporary waste rock dump volume | 260 288 $m^3$ | 1 103 323 $m^3$ | 1 013 436 $m^3$ | 295 947 $m^3$ | 503 336 $m^3$ |
| Temporary waste rock dump height | 10 m | 10 m | 20 to 30 m | 20 to 30 m | 20 to 30 m |

| **Underground mining** | | | | |
|---|---|---|---|---|
| Infrastructure complexes | | | **Kimberley Reef East** | **Bird Reef Central** |
| Location | | | See **Figure 2-3** | See **Figure 2-3** |
| Coordinates | A | Longitude | 27° 51' 44.97"E | 27° 53' 47.58"E |
| | | Latitude | 26° 10' 32.99"S | 26° 12' 2.20"S |
| | B | Longitude | 27° 51' 43.91"E | 27° 53' 57.31"E |
| | | Latitude | 26° 10' 36.95"S | 26° 12' 4.07"S |
| | C | Longitude | 27° 51' 49.45"E | 27° 53' 54.84"E |
| | | Latitude | 26° 10' 36.91"S | 26° 11' 59.19"S |
| | D | Longitude | 27° 51' 50.56"E | 27° 53' 50.52"E |
| | | Latitude | 26° 10' 32.99"S | 26° 11' 56.98"S |
| Mining sequence | | | 1 | 2 |
| Infrastructure complex size | | | ~ 3.5 ha | 2.19 ha |
| Size of mining area | | | ~ 100 ha | ~ 52 ha |
| Mining rate (per month) | | | 15 000 tonnes | 15 000 tonnes |
| Workings depth | | | 100 m to interception of reef (up 3 km below surface) | 100 m to interception of reef (up 3 km below surface) |
| Mining duration | | | 20 years | 10 years |
| Waste rock | | | All waste rock will remain in the underground workings. | All waste rock will remain in the underground workings. |

The mine plan presented in and assessed in this report and detailed in the Mining Works Programme (MWP) are associated with the planned open mine pits named Kimberley Reef East, 11 Shaft Main Reef, Rugby Club Main Reef, Mona Lisa Bird Reef and Roodepoort Main Reef, and Kimberley Reef East and Bird Reef Central Underground mine workings (see Figure 2-1 - Figure 2-3).

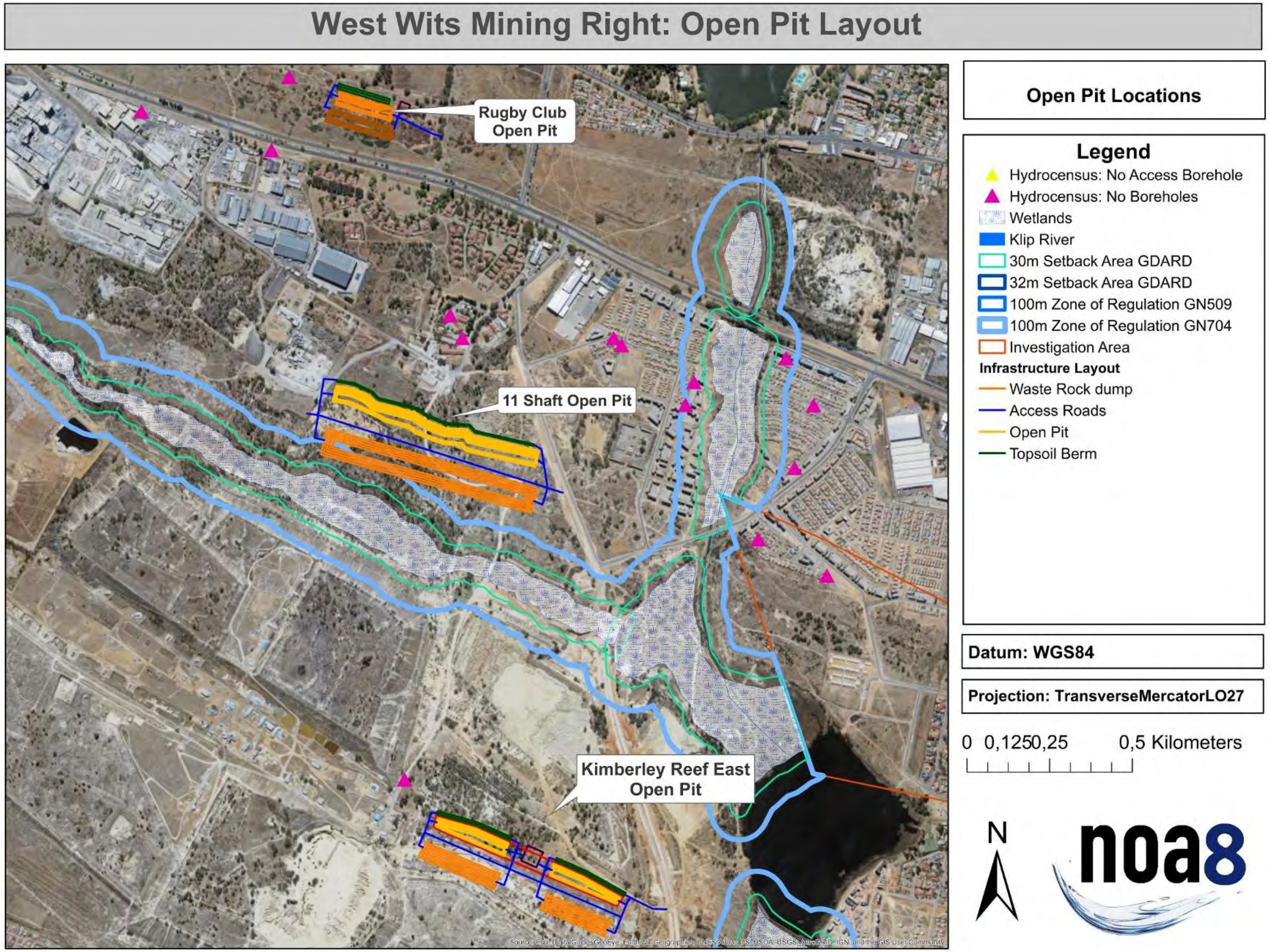


Figure 2-1 Kimberley Reef East, 11 Shaft and Rugby Club open pit mine layouts

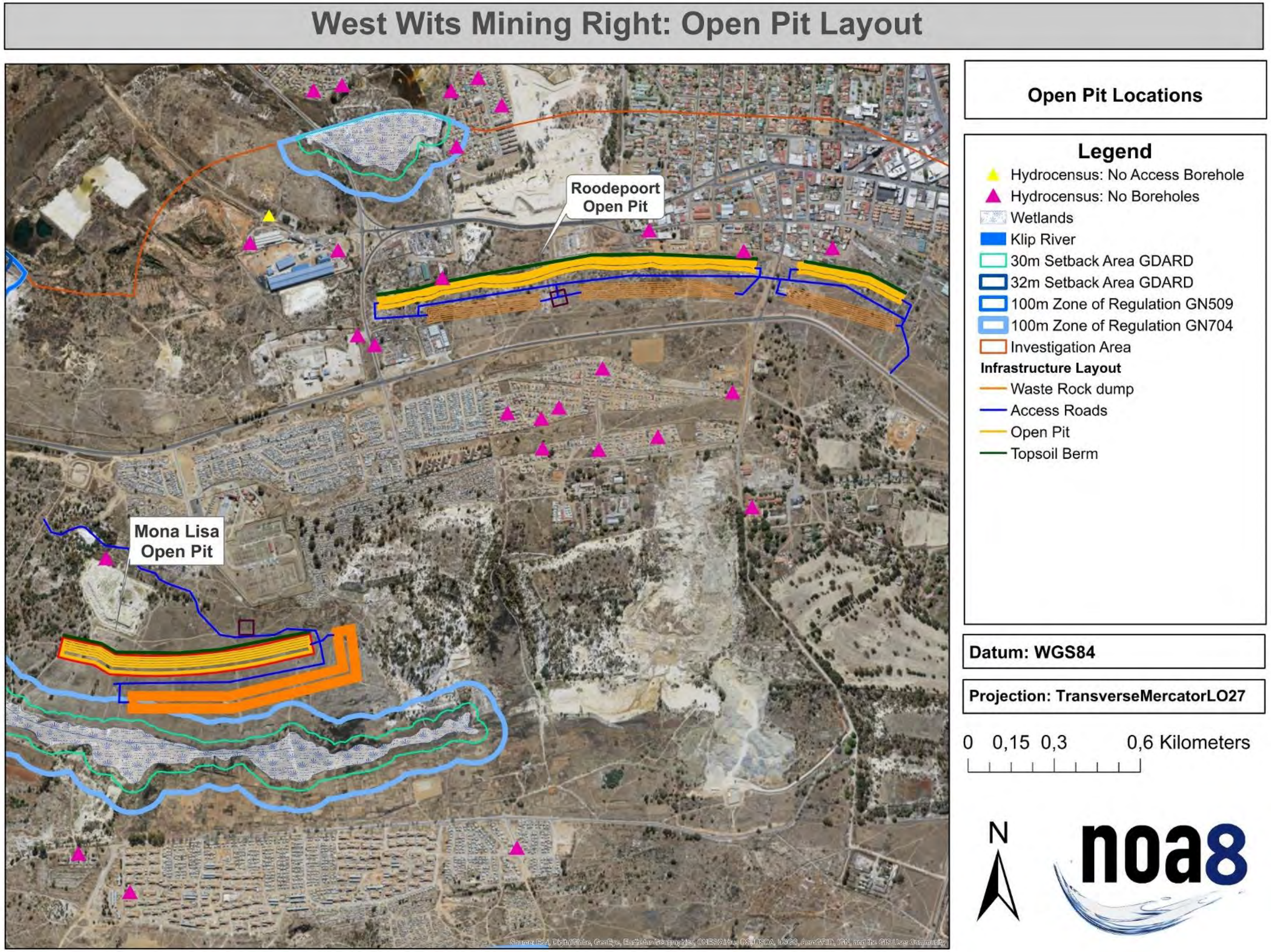


Figure 2-2 Mona Lisa and Roodepoort open pit mine layouts

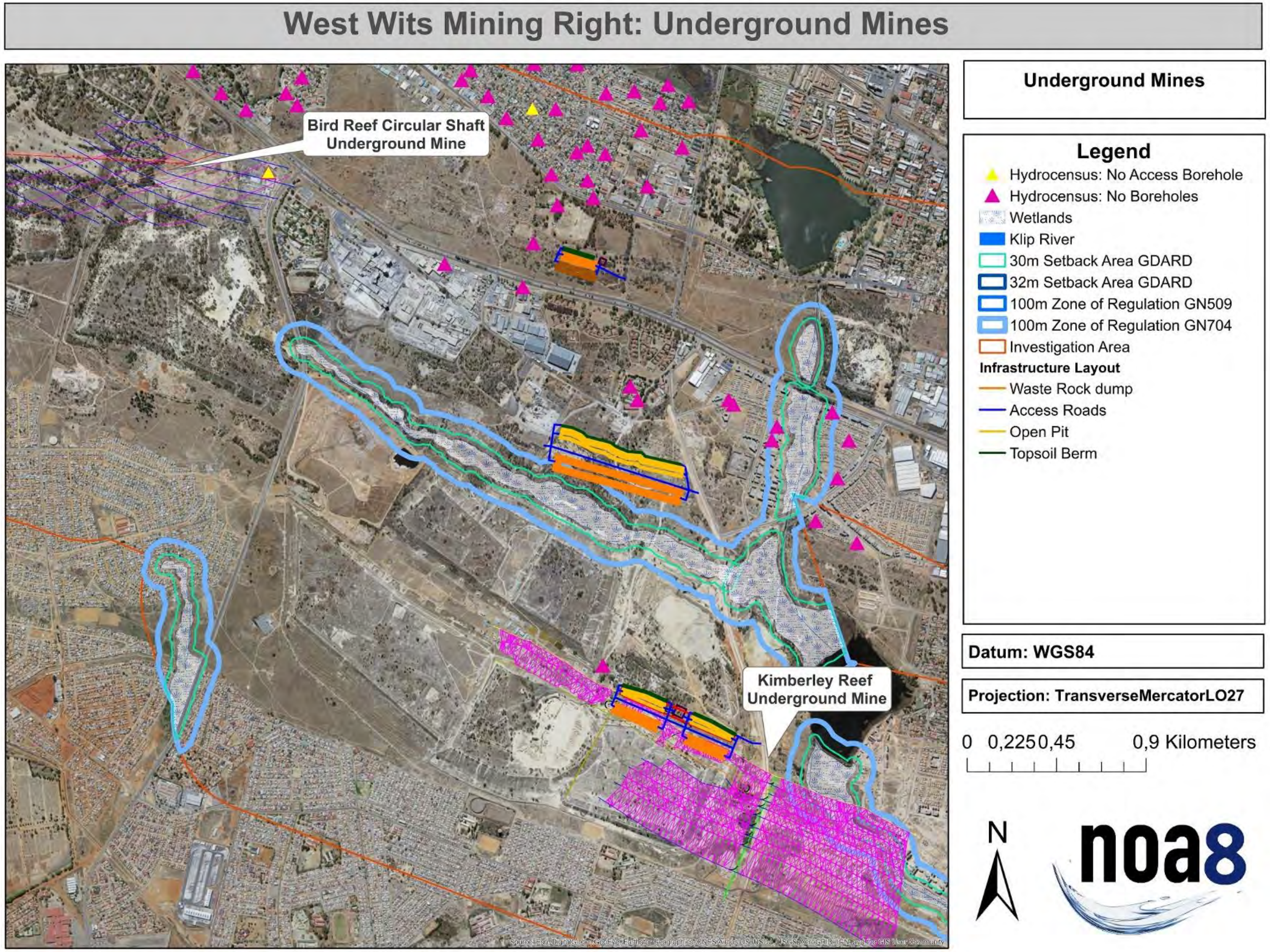


Figure 2-3 Undergound mine workings (Kimberley Reef East and Bird Reef Central) locations

The resources at the open pit targets are generally outcropping and production can commence at the onset of mining activities. Open pit mining activities will be performed by a mining contractor.

At the open pit target, no municipal or potable water is utilised in the operation and therefore no activities at these sites have an impact on water cost. Managerial and supervision during the construction and operational phase will be performed from the existing Sol Plaatje operation site. No additional infrastructure is therefore required. Primary mineral processing will take place on site, where ore will be crushed prior to transportation off-site. All run-of mine material will be transported to an existing processing plant off-site for concentrating of minerals.

# 3 Literature Review

Available geological and hydrogeological reports (see References – Section 15) were reviewed to gain a better understanding of the local geological and hydrogeological characteristics.

The National Groundwater Archive (NGA) was accessed to identify existing borehole and aquifer information associated with the West Wits Project area. The NGA search indicated only two geo-sites located within a radius of 5 km from the proposed mining areas (Table 3-1).

Table 3-1 DWS NGA data

| Identity | Latitude | Longitude | Farm Name | Measurement Date and Time | Water Level |
|---|---|---|---|---|---|
| 25175 | -26.18665 | 27.89744 | FLORIDA | | |
| 2627BB00067 | -26.15610 | 27.88717 | SUB 1 | 1974/06/19 8:00 | 12.00 |

The Department of Water and Sanitation (DWS) is the custodian of the national dolomite monitoring programme and surface and groundwater levels and qualities are recorded on a quarterly basis from dedicated boreholes and stream localities.

The proposed mining area is associated with the Zuurbekom and Upper Klip River dolomitic compartments and monitoring data associated with these compartments were also sourced from the DWS. Groundwater level data for 18 monitoring sites were available. The sites are between 9.5 km and 20 km from the proposed mining area and no groundwater quality information was available for these sites. Borehole yields, detailed construction and geology information was not available on the system. The data is discussed in Section 6.3.

A hydrocensus was conducted in 2018 to collect information on current groundwater conditions and use.

# 4 Limitations and Assumptions

The sub-catchment within which the proposed mining activities is located is a relatively large area, and even though there are boreholes that were identified in the study area during the hydrocensus there is still a shortage of detailed geology and aquifer information to help define the current groundwater conditions in the area. In addition, the geological information database is restricted to the proposed mining area and there is little information available on the regional geological conditions and structural controls. Some assumptions had to be made:

1. Aquifer homogeneity: It is assumed that the aquifers that occur in the area are relatively homogenous and compartmentalised; and
2. It is assumed that the mining areas that were rehabilitated could still have an impact on the groundwater flow patterns, and therefore also the contaminant migration through the study area. Details in terms of the older and neighbouring mines are however not available.

There are some assessment uncertainties which include:

1. Historical and current mining activities in the area have generated a lot of valuable groundwater level, abstraction and quality data. This informational was not available for this assessment since the surrounding mines refrained from sharing this information at the time of compiling the assessment.
2. Historical drilling and aquifer test data was not available for interpretation of the local geological horizons, depth of weathering and aquifer yields.

# 5 Environmental Setting

South Africa's gold mining industry commenced in the 1880s and played a strong role in creating some of the country's most important historical milestones, while shaping certain sectors of South African society.

Mining in the Central Basin of the Witwatersrand Goldfields started 132 years ago after the discovery of gold in 1886. The Central Basin stretches approximately 47 km from Roodepoort in the west to Germiston in the east. The proposed mining area is located south of Roodepoort, and on the northern boundary of Soweto; approximately 15 km west of Johannesburg city centre.

The greater West Wits Project area is dominated by rolling plains with interspersed hills, with a dominant hill crest in the north where previous mining activities have impacted on the outcrop. The average height above sea level for the area ranges from 1 600 – 1 780 m. Historical mining activities have altered the natural topography of the area.

The proposed project area is located within an area that has a history of mining operations, mine dumps, industrial activities and urban areas, as well as informal/illegal settlements and mining activities.

## 5.1 Catchment

The proposed mining area fall within the Upper Vaal Water Management Area (WMA 05), in quaternary catchment C22A. The Klip River drains the catchment in a southerly direction and flows along the western boundary of the proposed mining area (**Error! Reference source not found.**Figure 5-1). Six tributaries to the Klip River drain the area and include the Harringtonspruit that drains the Eldorado Park area and the Diepkloofspruit and Baileyspruit that drain the eastern portions of the sub-catchment. Along the Klip River are several wetland areas and dams.

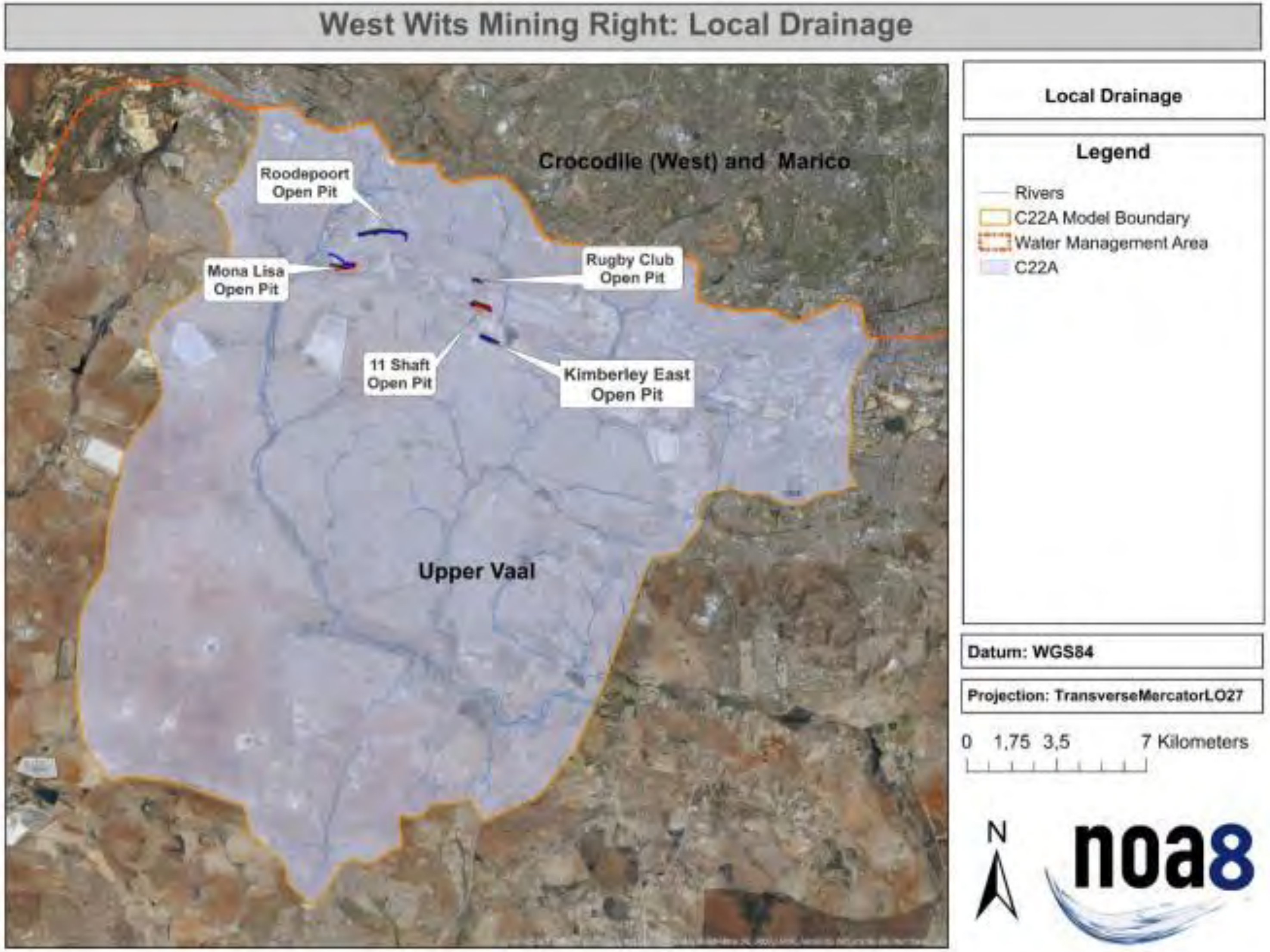


Figure 5-1 Local drainage

The Klip River Forum is constituted in terms of the National Water Act, 1998 (Act 36 of 1998) and is a non-profit organisation consisting of stakeholders actively participating in sustainable water resource management of the Klip River Catchment and its associated tributaries.

Under this Klip River Forum, there are in-stream water quality objectives (WQO) which have been set up to assist with water resources management. These are referenced in this report (Table 6-5). Stream water qualities are monitored on a regular basis by the DWS, Rand Water, Ekurhuleni and the City of Johannesburg. The monitoring occurs on a quarterly basis except for the DWS that does monthly sampling.

There are no DWS stream flow gauges within a five km radius that can be utilised to understand the flow of water close to the site. Although the DWS database indicates stations within the C22A catchment, there are no records available. Therefore, no information was available for streamflow analysis for the Project site.

The C22A quaternary catchment's climate and runoff parameters have been extracted from the Water Research Commission (WRC) water resources studies and presented in Table 5-1 (WRC, 2005).

Table 5-1 Precipitation and Evaporation of the C22A Quaternary Catchment

| Quaternary Catchment | Total Area ($km^2$) | MAP (mm) | MAE (mm) | Rainfall Zone | Evaporation Zone |
|---|---|---|---|---|---|
| C22A | 548 | 683 | 1 523 | C2B | 11 A |

## 5.2 Climate and Rainfall

The study area is characterised by a Highveld climate, with summer rainfall in the form of high intensity thunderstorms. Maximum temperatures average 26°C in January dropping to an average minimum of 16°C in June. Mean Annual Precipitation (MAP) for the area is 600 to 750 millimetres (mm) ~ 683 mm/a according to the Zuurbekom C2E007 rainfall station. The summer months (September to April) are characterised by hot days, summer thunderstorm activity and cool evenings. Winter (May to August) days are dry and nights are cold. Rain hardly falls in winter and the temperature occasionally drops to below zero at night, causing frost.

Recharge is defined as the process by which water is added to the zone of saturation of an aquifer. It is considered that recharge to the Witwatersrand Formation aquifers may be 1% to 2% of MAP (mean annual precipitation).

Recharge estimates for the dolomite generally fall in the 10% to 15% of the MAP range, with some values in the 20% to 50% range. The latter often relates to areas characterised by sinkholes and subsidence development, lowering of water levels and widening of conduits that may lead to an enhanced recharge potential (DWAF, 2006).

There are several routes by which precipitation recharges groundwater in the study area. In addition to direct recharge in open veld, parks and gardens, localized recharge often occurs along edges of paths and roads, where no formal storm water drainage exists. Land covered by an impermeable surface decrease recharge.

Water supply infrastructure in urban settings results in large volumes of water circulating below the surface; together with subsequent disposal of most of this water in sewers or on-site facilities such as septic tanks. Water mains are prone to leakage because they are constantly pressurized. Rates of leakage of 20% to 25% are common (Lerner, 2002). This water is available for recharge and sometimes is equal to or exceeds the recharge derived from direct precipitation. This form of recharge unfortunately also contributes to aquifer contamination impacts.

The following is the evaporation rates for the area:

1. S-Pan Evaporation of 1 523 mm/a, and
2. Open Water Evaporation of 1 266.9 mm/a

# 6 Hydrogeological Setting

This chapter aims to provide a conceptual understanding to the underlying rock formations and associated groundwater occurrence and flow.

Groundwater occurrence in the Witwatersrand and Ventersdorp rocks or the quartzite are generally associated with zones of deep weathering or faulting and jointing. The depth of weathering is not known due to a lack of information. Groundwater is often encountered in both the saturated weathered material below the regional groundwater rest level and in the transition zone between weathered and fresh formations.

The local weathered aquifers generally support moderate yielding boreholes (less than 1 L/s). Most fault and joint zones in the deeper fractured aquifers are steeply dipping structures that tend to narrow and even pinch out at depth, with a corresponding decrease in permeability. The porosity is usually less than 1% while the fresh rock may be regarded as impermeable.

The groundwater table on site is located approximately 25 to 30 meters below ground level (mbgl). Groundwater movement often mimics the topography and generally flows towards the south; the Roodepoort residential areas are thus located upstream from the proposed mining areas and the Bram Fischerville, Soweto residential areas and the dolomites downstream.

The dolomitic zone is characterised by highly fractured chert layers. The dissolution of calcite along fractures, together with folding and faulting, resulted in well-developed aquifers in the dolomite, with a high transmissivity and large storativity.

Dolomite has a reputation for its excellent water bearing properties. The development of secondary porosity within the dolomite is largely responsible for the permeability that it possesses. Circulating groundwater has further developed fractures and solution features of structural origin by carbonate solution. Large scale leaching and karstification of dolomite can result in very substantial storage of groundwater.

## 6.1 Geology

The mining targets are the auriferous conglomerates of the Central Rand Group, Witwatersrand Supergroup. These are the North Reef, Main Reef, Main Reef Leader, South Reef, Livingstone Reef, Bird Reef, Monarch Reefs, Kimberley Reefs, and Ventersdorp Contact Reef. The latter is situated at the base of the Ventersdorp Supergroup within the Venterspost Conglomerate Formation. The Central Rand Group is subdivided into the older Johannesburg (containing the Main, Randfontein, Luipaardsvlei, Krugersdorp, and Booysens formations) and the younger Turffontein (containing the Kimberley, Elsburg and Mondeor formations) subgroups.

The northern perimeter of the proposed mining area approximately follows the outcrop of the Johannesburg Subgroup, Central Rand Group. This package is overlain towards the south by strata of the Turffontein Subgroup. In the southwestern portion of the proposed mining area volcanic rocks of the Ventersdorp Supergroup outcrop. A circular outcrop comprised of Transvaal Supergroup sedimentary rocks is found just to the south of the central southern portion of the proposed mining area. These rocks predominantly consist of dolomite, with the Black Reef present at its base (Figure6-1).

Chert-rich dolomite has good groundwater potential, i.e. the Monte Christo and Eccles Formations. Constant re-circulation of groundwater is also causing enlargement of fractures and cavities, thus enhancing groundwater potential.

The Witwatersrand Basin holds the world's largest known gold reserves and having produced over 1.5 billion ounces. The basin straddles the North West, Gauteng and the Free State Provinces and is of the same period as the Vredefort impact of 2.023 Ga ago, and the Bushveld Igneous Complex.

Nearly half of all the gold ever mined has come from the extensive Witwatersrand Basin that was first found near Johannesburg in 1886. The gold occurs in reefs, or thin bands, that are mined at depths of down to 4 000 metres (m). Although many of the older mines are now exhausted, the Witwatersrand Basin (Wits Basin) still produces most of South Africa's gold. Silver and iridium are recovered as gold-refining by-products and the basin also has coal mines, although they are small players in the overall mining of the Basin.

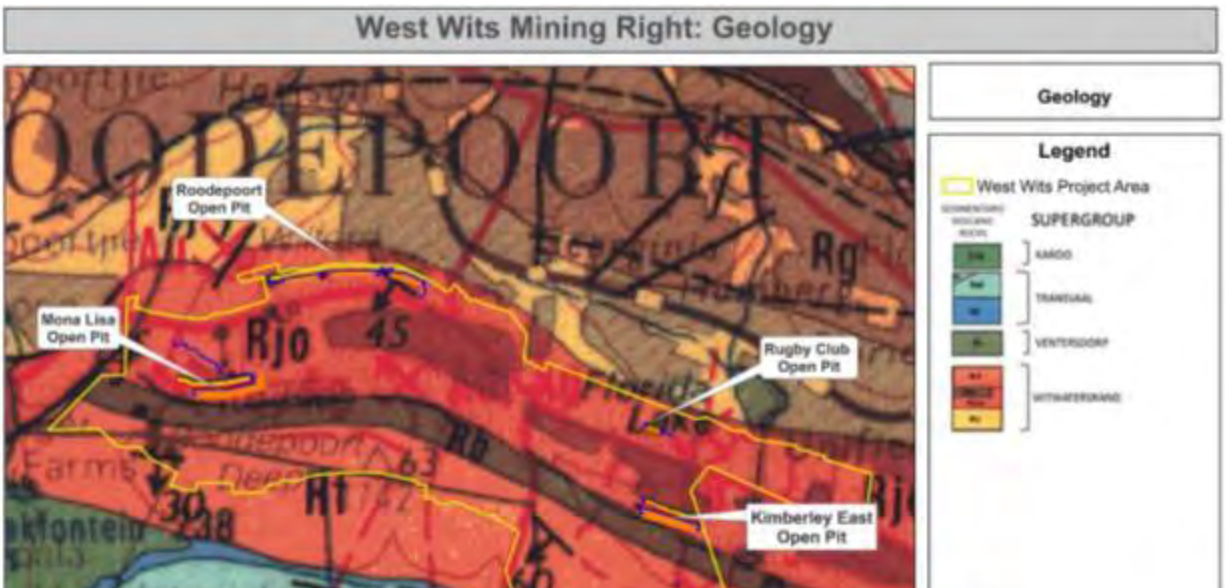

Figure6-1 Project area geology

The Wits Basin gold occurs almost exclusively within quartz pebble conglomerates. While the origins of the sedimentary layers of the Wits Basin are generally agreed upon, there remains much contention as to how the gold itself got there.

Dotted outside the basin are older Archaean granites of between 3 and 3.2 Ga, some of which are exposed while the much younger Karoo System cover others. The Witwatersrand System is a sequence of shale, quartzite and conglomerates ranging in age from 2.7 Ga for the Hospital Hill subgroup to 2.4 Ga for the Turffontein subgroup (Figure 6-2). The Lower Witwatersrand is composed mainly of argillaceous clays and shale with occasional banded ironstone, a tillite and an intercalated lava flow, while the Upper Witwatersrand consists almost entirely of quartzite and conglomerate, with its own volcanic horizon.

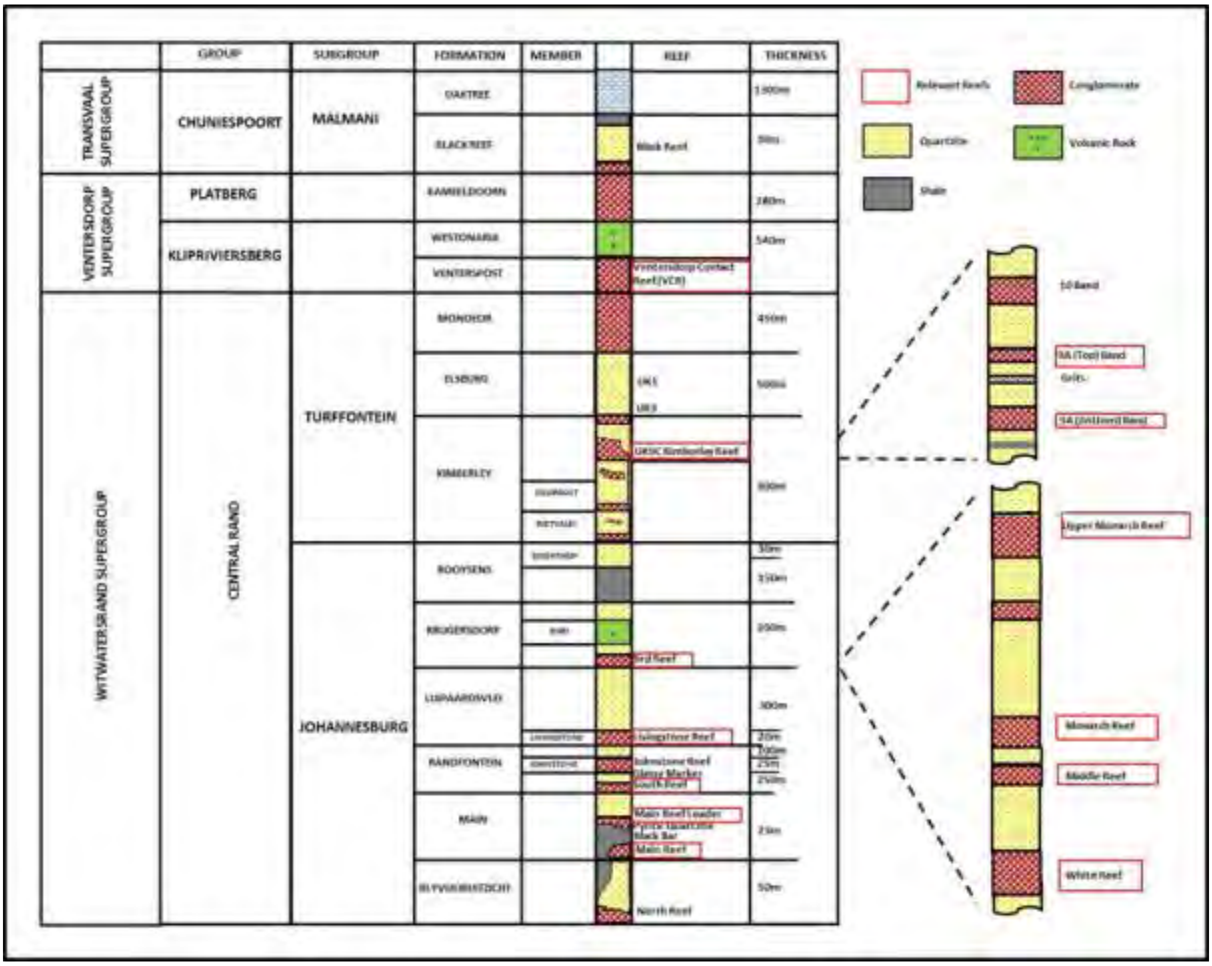


Figure 6-2 Stratigraphic column of the Central Rand Group in the Central Rand Goldfield

Extensive exploration has been conducted across the proposed mining area since February 2007. West Wits has a comprehensive knowledge of the local resource. A database evaluation revealed that 1 796 sample entries qualify for resource estimation. Consequently, West Wits was able to estimate resources that are defined in accordance with the 2012 JORC code. Mineral resource maps have been defined for all future mining areas.

The dolomite in the proposed mining area belongs to the Malmani Subgroup of the Transvaal Sequence. It is comprised of four Formations, with the subdivision being based on chert content and presence/absence and type of algal structures. From a groundwater perspective, the chert content is the most important, with the chert-rich formations forming the main aquifers.

A characteristic of the area is a series of cross-cutting lineaments representing faults and dykes. The dykes are not 100% impermeable, but are at least several orders of magnitude less permeable than the dolomite. They therefore divide the dolomite into a series of characteristic compartments. Of relevance to the proposed mining area are the Zuurbekom and Upper Klip River dolomitic compartments. The Klip River dyke bisects the proposed mining area. It runs from the centre of Roodepoort, across the circular dolomitic deposit and down to the centre of Lenasia. The dolomite to the east of the dyke is known as the Upper Klip River Compartment and to the west as the Zuurbekom Compartment.

The dolomite owes its permeability mainly to secondary fissures such as faults, joints and bedding planes which have provided easy access to circulating groundwater, thus promoting deep weathering of the dolomite, largely by carbonate solution or karstification. The residues of this weathering are mainly brown clays and wad with chert rubble and boulders. The depth of weathering/superficial deposits varies up to approximately 150 m, but is very unpredictable and pinnacles of fresh dolomite are commonplace adjacent to deeply weathered zones. One of the most important controls on zones of deep weathering is tensional fractures.

These dykes are of diabase or composite syenite-diabase and are associated with the Pilanesberg Dykes (Day, 1980). These N-S dykes occupy major tensional features. They form barriers to groundwater flow of varying effectiveness.

A third structural feature controlling groundwater occurrence are axes of local folding. Flexure of the formations caused a network of fissures which radiate upwards from the axes of these distortions. Such localised folding is mainly detected from detailed exploration borehole records where the boreholes penetrate through the rock.

## 6.2 Hydrocensus

A hydrocensus was conducted across the Project area during March 2018. The survey included the proposed mining footprint areas and adjacent properties and concentrated on identifying existing boreholes to enhance the knowledge of the groundwater systems and current groundwater use.

During the 2018 hydrocensus 13 boreholes were identified (Table 6-1, Table 6-2 and Appendix B). Another 123 properties were assessed, but the land owners indicated no boreholes (Appendix B); most sites receive their water from municipal supply. Groundwater level measurements were possible from four boreholes. The 13 sites included:

1. three boreholes which are in use;
2. one borehole where the equipment broke in 2000 and has not been used since;
3. one open / capped borehole;

4. one monitoring borehole;
5. one borehole where the owner did not want to share the borehole information; and
6. six boreholes where access was not granted and information is thus unknown.

During the hydrocensus the following information was collected for each site:

1. Borehole position (X, Y, Z-coordinates);
2. Information relating to equipment installed;
3. Borehole construction details;
4. Borehole yield – if known;
5. Groundwater level, if possible; and
6. Current use.

Detail of the sites identified during the 2018 hydrocensus is available in section 16 Appendix A: Hydrocensus Data and presented in Figure 6-3. Water levels were measured by using a dip meter to measure the distance from the mouth of the borehole (borehole collar elevation) to the groundwater table depth in the borehole. The height of the borehole collar was subtracted from the measured water level to define a water level below surface (measured in m bgl) (Appendix A: Hydrocensus Data).

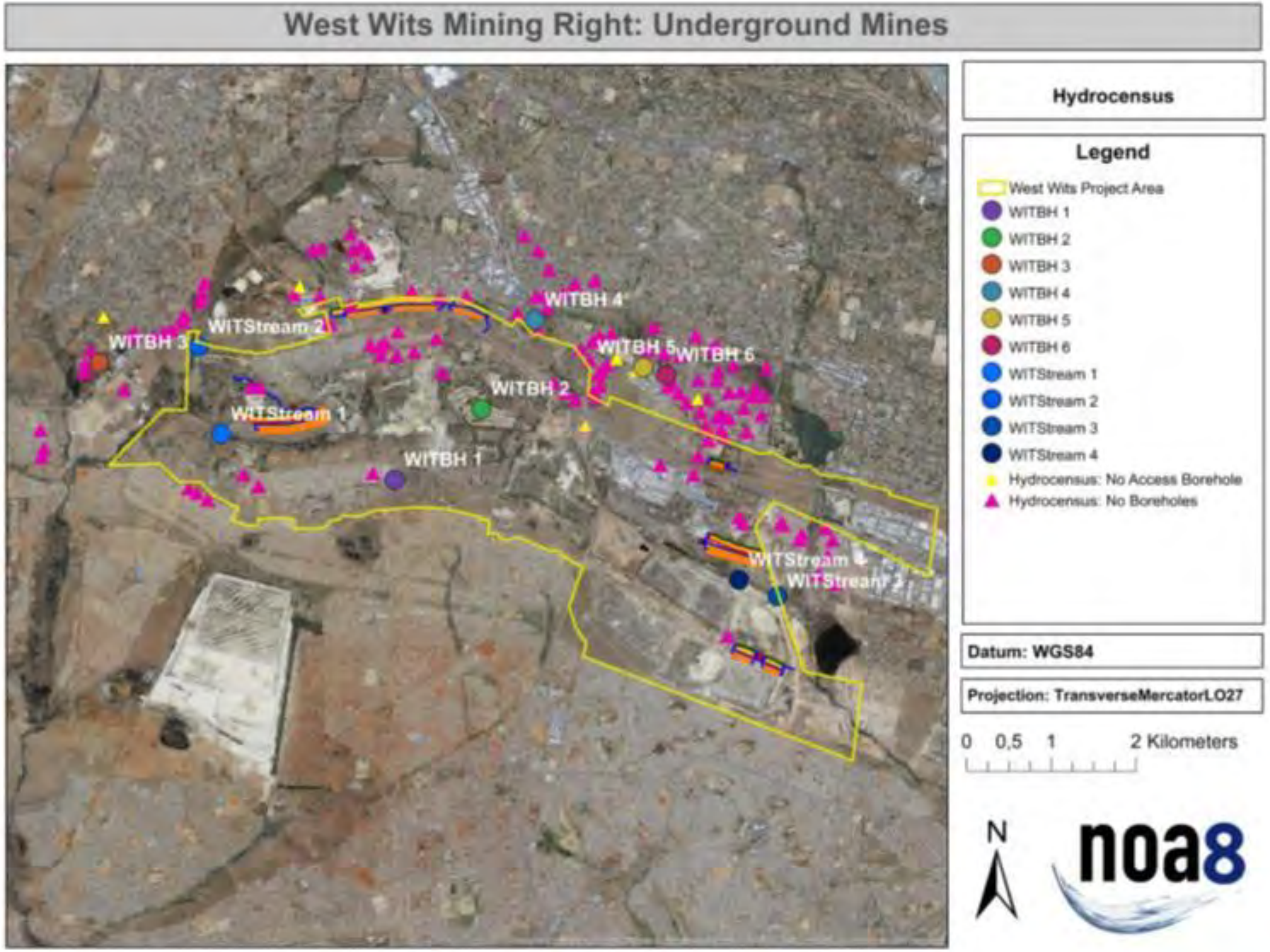


Figure 6-3 Locations recorded and sampled during the 2018 hydrocensus (Table 6-1)

Table 6-1 2018 Hydrocensus summary – access allowed (Figure 6-3)

| Number | Coordinates | | Water level (mbgl) | Water use | Comments | Contact Name | Sample Taken | Time | Date |
|---|---|---|---|---|---|---|---|---|---|
| | S | E | Static | | | | | | |
| WITBH 1 | 26,18319 | 27,85684 | 36,215 | No pump equipped,45m water strike | Open well, recently drilled for future use | Mr A Cronje | Yes | 10:29 | 26-Mar-18 |
| WITStream 1 | 26.17845 | 27,83636 | | None | Stream on Eastern side of Mona Lisa, Stream flowing West | | Yes | 11:42 | 26-Mar-18 |
| WITBH 2 | 26,17559 | 27,86703 | | Toilets at Golf club. | Hole pump for 20min, wait for 1 hour to recharge, pump again for 20mins | Mark Anthony (Manager) | Yes | 9:20 | 27-Mar-18 |
| WITBH 3 | 26,1709 | 27,82188 | | Domestic and Swimming pool | Not using Municipal at all | Mr J H W Pretorius | Yes | 10:40 | 27-Mar-18 |
| WITStream 2 | 26,16916 | 27,8336 | | None | Stream on Most Western point of Zamma Zamma Mining from Mona Lisa | | Yes | 11:33 | 27-Mar-18 |
| WITBH 4 | 26,16607 | 27,87327 | 11,9 | Domestic | Owner did not want to give out any info | Mr Sam Mohlakeng | Yes | 14:19 | 27-Mar-18 |
| WITStream 3 | 26,19532 | 27,90214 | | None | Stream to the Eastern side of Kimberley and 11 Shaft, stream flowing East | | Yes | 9:43 | 28-Mar-18 |
| WITStream 4 | 26,19361 | 27,8976 | | None | Stream on Western side of 11 Shaft | | Yes | 10:16 | 28-Mar-18 |
| WITBH 5 | 26,17104 | 27,88611 | 7,7 | None | Pump broke in 2000, not used since | Mr N J Davids | Yes | 14:07 | 28-Mar-18 |
| WITBH 6 | 26,17184 | 27,88884 | 4,46 | Only for garden | Brownish water, says it clears up after a while | Mr A C Gregory | Yes | 15:00 | 28-Mar-18 |

Table 6-2 Hydrocensus summary – no access

| Name | Site | Street Address | Comments | Coordinates | | Time | Date |
|---|---|---|---|---|---|---|---|
| Private | Borehole | Plot 36 Reyger Street | Windpump, nobody home | 26,16608 | 27,82235 | 11:03 | 27 March 2018 |
| UMC 12 | Mon Well | North of Piki Tup Penny Road | Well locked with padlock, no water level | 26,16263 | 27,84549 | 12:10 | 27 March 2018 |
| Laerskool Die Ruiter | Borehole | Cnr Albert Sisulu and Lyon Street, Roodepoort | Principal has left for holiday, can make appointment 10th of April | 26,17012 | 27,88294 | 11:43 | 28 March 2018 |
| Rolbal Club | Borehole | Tornado Crescent, Roodepoort | Closed, no answer at intercom gate | 26,16717 | 27,87951 | 12:02 | 28 March 2018 |
| Hope Restoration Ministries | Borehole | Albert Sisulu Road next to Die Ruiter | Gardener said he's not allowed to open gate, can make appointment 30th March | 26,17142 | 27,88522 | 13:36 | 28 March 2018 |
| Private | Borehole | 13 Flamingo Street, Roodepoort | Nobody at home | 26,17435 | 27,89256 | 9:03 | 29 March 2018 |
| Afrisam | Borehole | Main Reef Road | Neels Venter, on leave for long weekend, contact him on 3rd April, Phone 011758600, Aquatico is doing monthly monitoring on Site. | 26,17732 | 27,87931 | 11:44 | 29 March 2018 |

## 6.3 Groundwater Levels

Based on the 2018 hydrocensus survey the groundwater levels in the project area and surrounds vary between 4.4 m bgl at borehole WITBH 6 and 36.2 m bgl at borehole WITBH 1. Borehole WITBH 6 is located upstream from the proposed mining area, in the Hamburg residential area. Borehole WITBH 1 is located south of the Durban Deep Golf Course. The hydrocensus data plus the information collected from the DWS's NGA indicate groundwater levels between 4.5 m and 12 m in the Roodepoort residential areas. Time series groundwater level or quality data are not available for any of these boreholes to determine seasonal groundwater changes.

Time series groundwater levels information is however available for the 18 dolomite monitoring stations (Table 6-3). Groundwater in the Klip River area can be divided into numerous small compartments based on groundwater levels. These compartments appear to be in connection with the Klip River. Gradients vary from approximately 0.1% to approximately 0.2% (DWS, 2006).

Groundwater level data was sourced for 18 monitoring sites – 4 boreholes are in the Upper Klip River compartment and 14 boreholes in the Zuurbekom compartment. In terms of the proposed mining project the Zuurbekom compartment would have reference. The closest dolomite monitoring point is C2N0023, located approximately 7.5 km southwest from the big slimes dam located in Bram Fischerville and approximately 2 km east of the Cooke Plant.

Table 6-3 DWS dolomite monitoring stations

| HSTA Number | Farm Name | Latitude | Longitude | Quaternary Drainage Region |
|---|---|---|---|---|
| C2N0023 | Luipaardsvlei | -26.23882 | 27.76044 | C23D |
| C2N0310 | Zuurbekom | -26.26674 | 27.75401 | C22A |
| C2N0317 | Johannesburg | -26.29708 | 27.83529 | C22A |
| C2N0320 | Luipaardsvlei | -26.22568 | 27.75613 | C23D |
| C2N0325 | Luipaardsvlei | -26.24529 | 27.74044 | C23D |
| C2N0327 | Zuurbekom | -26.28683 | 27.78506 | C22A |
| C2N0347 | Zuurbekom | -26.26776 | 27.76297 | C22A |
| C2N0348 | Zuurbekom | -26.27321 | 27.76983 | C22A |
| C2N0349 | Zuurbekom | -26.27668 | 27.76584 | C22A |
| C2N0612 | ZUURBEKOM (W.R.L.H.) | -26.28568 | 27.75892 | C22A |
| C2N0614 | Zuurbekom | -26.29492 | 27.76978 | C22A |
| C2N0615 | Zuurbekom | -26.29763 | 27.7895 | C22A |
| C2N0619 | Johannesburg | -26.288 | 27.8139 | C22A |
| C2N0622 | Zuurbekom | -26.29589 | 27.80518 | C22A |
| C2N0835 | Rietfontein | -26.34619 | 27.87807 | C22A |
| C2N0836 | Olifantsvlei | -26.33475 | 27.90583 | C22A |
| C2N1097 | Lenasia | -26.31647 | 27.8318 | C22A |
| C2N1098 | Lenasia | -26.32476 | 27.84503 | C22A |

These dolomite monitoring stations are far from the proposed development and should not be impacted by any of the proposed mining activities. The groundwater level trends observed in these monitoring boreholes could potentially apply to any borehole within the proposed development area that penetrate the dolomite. The time-series data clearly show periods when the water table is much shallower (potentially good recharge periods) compared to dryer periods when the water table is deeper. The trend is visible in most monitoring sites and therefor the trend is not linked to abstraction activities, but rather seasonal and climatic conditions. The water level monitoring data is appended to Appendix C.

The monitoring data indicates groundwater levels varying between 11 and 55 m bgl. The average water levels are approximately 25 to 30 m bgl. This relates to the areas south of the proposed mining areas and located directly on the dolomite.


Figure 6-4 Groundwater level data – borehole C2N0320

One of the key aspects of areas underlain by dolomite is ground stability. This relates to critical variations or fluctuations in the water table. In areas where the original water table is within 30 m of the surface, fluctuations up to 5 m have been found to be acceptable. Fluctuations beyond this can lead to ground instability and sinkhole development, with sometimes catastrophic results.

## 6.4 Groundwater Quality

Groundwater samples were collected from six boreholes and four streams during the 2018 hydrocensus survey. The water samples were analysed for basic inorganic parameters and E.Coli and the results were compared against the SANS 241:2015 Drinking Water Standards (Table 6-4), as well as the Klip River WQO (Table 6-5). The borehole test certificates are attached in Appendix B: Water quality certificates.

Based on the water quality results (Table 6-4) the following conclusions were drawn:

1. Groundwater sampled from 5 of the 6 boreholes are not suitable for human consumption. It was only WITBH 5 that presented element concentrations below the chronic / acute health limits. Manganese was slightly elevated in borehole WITBH 5, but the concentration (0.12 mg/L) is only of aesthetic concern.
    a. Borehole WITBH 1 – this borehole is not currently in use. It was recently drilled for use at the Blueprint facility. The water quality does indicate high concentrations of sulphate, lead, manganese, nickel and dissolved uranium. These elements are present in concentrations exceeding the chronic / acute health limits. The pH was very low (3.4), with aluminium, calcium and ammonia also present in elevated concentrations.
    b. Borehole WITBH 2 – this borehole is used at the Golf Club as water supply to the toilets. The water quality does indicate high concentrations of sulphate, nickel and dissolved uranium. These elements are present in concentrations exceeding the chronic / acute health limits. The pH was near neutral (6.6) and calcium, magnesium, manganese and zinc were present in elevated concentrations. Boreholes WITBH 1 and WITBH 2 are located within the proposed mining area and the poor water quality potentially reflects historical and current mining and industrial impacts.
    c. Borehole WITBH 3 – this borehole is currently the only source of water to this private property. The water quality does indicate very high concentrations of E.Coli. The bacteria concentrations exceed the acute health limits. The rest of the elements were recorded in concentrations below the drinking water limits. The cause is unknown and could relate to the nearby stream and wetlands or septic tanks and sewage present in the local aquifers.
    d. Borehole WITBH 4 – the use of this borehole is currently not known as the owner of this private property did not want to share the information. The water quality does indicate very high concentrations of E.Coli and nitrate. The bacteria concentrations exceed the acute health limits. The rest of the elements were recorded in concentrations below the drinking water limits. The borehole is located close to a local cemetery.
    e. Borehole WITBH 6 – this borehole is used for garden irrigation in the Hamburg residential area. The water quality does indicate high concentrations of dissolved uranium. The uranium is present in concentrations exceeding the chronic health limits. Calcium was also present in elevated concentrations.
    f. Private borehole owners should be advised of the quality assessment outcome.
2. The four surface water samples indicate water that is not suitable for human consumption. Sampling point WITstream 2 indicates high E.Coli, but the rest of the elements are within drinking water limits. This sampling points is along the upper reaches of the Klip River, where it passes under the R41, Randfontein Road.
    a. Surface water sample WITstream 1 – this sampling point is in the tributary

flowing westwards from the Golf Course area. The water quality does indicate high concentrations of sulphate, manganese, nickel and dissolved uranium. These elements are present in concentrations exceeding the chronic / acute health limits. The pH was very low (4.5), with aluminium, calcium and ammonia also present in elevated concentrations.

b. Surface water sample WITstream 3 – this sampling point is in a tributary flowing eastward through the Vogelstruisfontein area and draining the proposed mining area. The water quality does indicate high concentrations of sulphate, lead, manganese, nickel, nitrate and dissolved uranium. These elements are present in concentrations exceeding the chronic / acute health limits. The pH was very low (3.4), with aluminium, calcium, iron, magnesium, potassium and ammonia also present in elevated concentrations.
c. Borehole WITstream 4 – this sampling point is in a tributary flowing eastward through the Vogelstruisfontein area and draining the proposed mining area. The sampling point is upstream from sampling point WITstream 3. The water quality does indicate high concentrations of sulphate, lead, manganese, nickel and dissolved uranium. These elements are present in concentrations exceeding the chronic / acute health limits. The pH was very low (3.3), with aluminium, calcium, iron, magnesium, potassium and ammonia also present in elevated concentrations.
d. The two tributaries draining the proposed mining area are contaminated by historical and possibly current mining and industrial activities and the water must not be used unless treated. A possible source of the poor-quality water is the old tailings facilities in this area.

The chemicals of concern for the project area are:

1. Sulphate;
2. Lead;
3. Manganese;
4. Nickel;
5. Dissolved uranium;
6. E.Coli; and
7. Nitrate.

These elements are present in concentrations exceeding the chronic / acute health limits.

The following elements were also present in elevated concentrations:

1. Aluminium;
2. Calcium;
3. Iron;
4. Magnesium;
5. Potassium; and
6. Ammonia.

Based on the SANS241 drinking water guideline the sampled groundwater and surface water is not fit for human consumption (unless treated). Table 6-5 presents the same water quality results but compared to the Klip River Water Quality Objectives standards. The conclusions remain the same and highlights the poor quality of the water resources.

Table 6-4 Hydro-chemical results

| Determinant | Unit | SANS 241 Standards Limits | | DWS Drinking Standards | WESTWITS WITBH 1 26.03.18 | WESTWITS WITBH 2 26.03.18 | WESTWITS WITHBH 3 26.03.18 | WESTWITS WITBH 4 26.03.18 | WESTWITS WITBH 5 26.03.18 | WESTWITS WITBH 6 26.03.18 | WESTWITS WITSTREAM 1 26.03.18 | WESTWITS WITSTREAM 2 26.03.18 | WESTWITS WITSTREAM 3 26.03.18 | WESTWITS WITSTREAM 4 26.03.18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | WITBH 1 | WITBH 2 | WITBH 3 | WITBH 4 | WITBH 5 | WITBH 6 | WITStream 1 | WITStream 2 | WITStream 3 | WITStream 4 |
| pH at 25°C | pH units | ≥5 - ≤9.7 | | | 3.4 | 6.6 | 6.4 | 7.0 | 6.5 | 6.9 | 4.5 | 7.0 | 3.4 | 3.3 |
| Electrical Conductivity at 25°C | mS/m | Aesthetic ≤170 | | | 187 | 132 | 11.7 | 18.9 | 9.7 | 50 | 103 | 32 | 306 | 293 |
| Chloride | mg Cl/ℓ | Aesthetic ≤300 | | | 37 | 36 | 12.6 | 16.7 | 3.78 | 28 | 26 | 19.8 | 227 | 249 |
| Sulphate | mg $SO_4$/ℓ | Aesthetic ≤250 | Acute health ≤500 | | 1144 | 742 | <0.21 | 2.02 | 8.40 | 74 | 597 | 83 | 1392 | 1322 |
| Fluoride | mg F/ℓ | | Chronic health ≤1.5 | | <0.03 | 0.99 | 0.05 | 0.09 | 0.21 | 0.13 | <0.03 | 0.10 | <0.03 | <0.03 |
| Orthophosphate | mg P/ℓ | | | | 0.06 | <0.04 | 0.15 | 0.11 | 0.66 | 0.04 | 0.84 | <0.04 | 0.77 | <0.04 |
| SANS | mg N/ℓ | | | | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 |
| Saline Ammonia | mg N/ℓ | | | | 1.69 | 0.24 | <0.11 | <0.11 | 0.31 | <0.11 | 7.88 | <0.11 | 48 | 15.3 |
| Cyanide (Total) | µg CN/ℓ | | Acute health ≤200 | | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Dissolved Aluminium | mg Al/ℓ | Operational ≤0.3 | | | 60 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 5.00 | <0.02 | 11.4 | 14.0 |
| Dissolved Antimony | mg Sb/ℓ | | Chronic health ≤0.02 | | <0.009 | 0.01 | 0.01 | <0.009 | 0.01 | <0.009 | <0.009 | 0.01 | <0.009 | 0.02 |
| Dissolved Arsenic | mg As/ℓ | | Chronic health ≤0.01 | | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 |
| Dissolved Barium | mg Ba/ℓ | | Chronic health ≤0.7 | | 0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 0.03 | 0.02 | <0.02 | <0.02 |
| Dissolved Beryllium | mg Be/ℓ | | | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Dissolved Boron | mg B/ℓ | | Chronic health ≤2.4 | | 0.13 | 0.07 | 0.05 | 0.03 | 0.03 | 0.04 | 0.11 | 0.07 | 0.34 | 0.31 |
| Dissolved Cadmium | mg Cd/ℓ | | Chronic health ≤0.003 | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Dissolved Calcium | mg Ca/ℓ | | | No health. Scaling intensifies from 32mg/L | 228 | 161 | 6.17 | 7.94 | 7.15 | 69 | 147 | 34 | 365 | 345 |
| Dissolved Chromium | mg Cr/ℓ | | Chronic health ≤0.05 | | 0.03 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Dissolved Cobalt | mg Co/ℓ | | | | 1.45 | 0.06 | <0.02 | <0.02 | <0.02 | <0.02 | 0.63 | <0.02 | 0.91 | 0.92 |
| Dissolved Copper | mg Cu/ℓ | | Chronic health ≤2 | | 0.70 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 0.06 | <0.02 | 0.17 | 0.13 |
| Dissolved Iron | mg Fe/ℓ | Aesthetic ≤0,3 | Chronic health ≤2 | | 0.07 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 1.46 | 1.88 |
| Dissolved Lead | mg Pb/ℓ | | Chronic health ≤0.01 | | 0.06 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | 0.04 | 0.06 |
| Dissolved Lithium | mg Li/ℓ | | | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Dissolved Magnesium | mg Mg/ℓ | | | Diarrhoea and scaling issues from 70mg/L | 65 | 82 | 5.93 | 14.9 | 1.71 | 18.6 | 29 | 11.0 | 84 | 85 |
| Dissolved Manganese | mg Mn/ℓ | Aesthetic ≤0,1 | Chronic health ≤0.4 | | 9.25 | 0.26 | <0.02 | 0.02 | 0.12 | <0.02 | 4.78 | 0.10 | 18.1 | 29 |
| Dissolved Mercury | mg Hg/ℓ | | Chronic health ≤0.006 | | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Dissolved Nickel | mg Ni/ℓ | | Chronic health ≤0.07 | | 2.16 | 0.29 | <0.02 | <0.02 | <0.02 | <0.02 | 1.72 | <0.02 | 1.35 | 1.28 |
| Dissolved Selenium | mg Se/ℓ | | Chronic health ≤0.04 | | <0.07 | <0.07 | <0.07 | <0.07 | <0.07 | <0.07 | <0.07 | <0.07 | <0.07 | <0.07 |
| Dissolved Silver | mg Ag/ℓ | | | | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Dissolved Strontium | mg Sr/ℓ | | | | 0.43 | 0.18 | 0.03 | 0.05 | 0.02 | 0.31 | 0.19 | 0.11 | 0.79 | 0.72 |
| Dissolved Thallium | mg Tl/ℓ | | | | 0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 0.02 | 0.03 |
| Dissolved Tin | mg Sn/ℓ | | | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Dissolved Titanium | mg Ti/ℓ | | | | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Dissolved Vanadium | mg V/ℓ | | | Not suitable over 1.0 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Dissolved Zinc | mg Zn/ℓ | Aesthetic ≤5 | | | 2.69 | 7.69 | 0.25 | 0.05 | 1.17 | 0.16 | 0.86 | 0.19 | 2.32 | 2.08 |
| Dissolved Zirconium | mg Zr/ℓ | | | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Potassium | mg K/ℓ | | | No aesthetic or health effects below 50mg/L | 13.0 | 7.06 | 0.46 | 0.91 | 8.79 | 2.19 | 7.23 | 5.47 | 90 | 98 |
| Sodium | mg Na/ℓ | Aesthetic ≤200 | | | 49 | 59 | 6.61 | 4.83 | 6.61 | 20 | 34 | 21 | 175 | 186 |

| Determinant | Unit | SANS 241 Standards Limits | | DWS Drinking Standards | WESTWITS WITBH 1 26.03.18 | WESTWITS WITBH 2 26.03.18 | WESTWITS WITHBH 3 26.03.18 | WESTWITS WITBH 4 26.03.18 | WESTWITS WITBH 5 26.03.18 | WESTWITS WITBH 6 26.03.18 | WESTWITS WITSTREAM 1 26.03.18 | WESTWITS WITSTREAM 2 26.03.18 | WESTWITS WITSTREAM 3 26.03.18 | WESTWITS WITSTREAM 4 26.03.18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | WITBH 1 | WITBH 2 | WITBH 3 | WITBH 4 | WITBH 5 | WITBH 6 | WITStream 1 | WITStream 2 | WITStream 3 | WITStream 4 |
| Dissolved Molybdenum | mg Mo/ℓ | | | | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 | <0.11 |
| Dissolved Uranium | mg U/ℓ | | Chronic health ≤0.03 | | 0.49 | 0.06 | <0.02 | <0.02 | <0.02 | 0.04 | 0.17 | 0.03 | 0.13 | 0.05 |
| E.coli | colonies per 100mℓ | | Acute health - Not detected | | 0 | 0 | 46 | 540 | 0 | 0 | 0 | 50 | 0 | 0 |
| Total Dissolved Solids at 180°C | Calc. mg/ℓ | Aesthetic ≤1200 | | | 1249 | 878 | 78 | 126 | 65 | 332 | 684 | 217 | 2041 | 1954 |
| Nitrate | mg N/ℓ | | Acute health ≤11 | | 9.78 | 2.40 | 4.20 | 12.6 | 0.77 | 10.0 | 0.06 | 1.30 | 31.5 | 2.20 |
| Ammonia | mg N/ℓ | Aesthetic ≤1.5 | | | 1.69 | 0.24 | <0.11 | <0.11 | 0.31 | <0.11 | 7.88 | <0.11 | 48 | 15.3 |

Table 6-5 Hydro-chemical results compared to Klip River WQO

| Determinant | Unit | Ideal Catchment Background | Acceptable Management Target | Tolerable Interim Target | Unacceptable | WITBH 1 | WITBH 2 | WITBH 3 | WITBH 4 | WITBH 5 | WITBH 6 | WITStream 1 | WITStream 2 | WITStream 3 | WITStream 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH at 25°C | pH units | 6 - 9 | | | <6; >9 | 3.4 | 6.6 | 6.4 | 7.0 | 6.5 | 6.9 | 4.5 | 7.0 | 3.4 | 3.3 |
| Electrical Conductivity at 25°C | mS/m | 80 | 80 - 100 | 100 - 150 | >150 | 187 | 132 | 11.7 | 18.9 | 9.7 | 50 | 103 | 32 | 306 | 293 |
| Chloride | mg Cl/ℓ | <50 | 50 - 75 | 75 - 100 | >100 | 37 | 36 | 12.6 | 16.7 | 3.78 | 28 | 26 | 19.8 | 227 | 249 |
| Sulphate | mg $SO_4$/ℓ | <200 | 200 - 350 | 350 - 500 | >500 | 1144 | 742 | <0.21 | 2.02 | 8.40 | 74 | 597 | 83 | 1392 | 1322 |
| Fluoride | mg F/ℓ | <0,19 | 0,19 - 0,7 | 0,7 - 1,0 | >1,0 | <0.03 | 0.99 | 0.05 | 0.09 | 0.21 | 0.13 | <0.03 | 0.10 | <0.03 | <0.03 |
| Dissolved Aluminium | mg Al/ℓ | | <0,3 | 0,3 - 0,5 | >0,5 | 60 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 5.00 | <0.02 | 11.4 | 14.0 |
| Dissolved Iron | mg Fe/ℓ | <0,5 | 0,5 - 1,0 | 1,0 - 1,5 | >1,5 | 0.07 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | 1.46 | 1.88 |
| Dissolved Magnesium | mg Mg/ℓ | <8,0 | 8 - 30 | 30 - 70 | >70 | 65 | 82 | 5.93 | 14.9 | 1.71 | 18.6 | 29 | 11.0 | 84 | 85 |
| Dissolved Manganese | mg Mn/ℓ | <1,0 | 1 - 2 | 2 - 4 | >4,0 | 9.25 | 0.26 | <0.02 | 0.02 | 0.12 | <0.02 | 4.78 | 0.10 | 18.1 | 29 |
| Sodium | mg Na/ℓ | <50 | 50 - 80 | 80 - 100 | >100 | 49 | 59 | 6.61 | 4.83 | 6.61 | 20 | 34 | 21 | 175 | 186 |
| Nitrate | mg N/ℓ | <2,0 | 2 - 4 | 4 - 7 | >7,0 | 9.78 | 2.40 | 4.20 | 12.6 | 0.77 | 10.0 | 0.06 | 1.30 | 31.5 | 2.20 |
| Ammonia | mg N/ℓ | <0,5 | 0,5 - 1,5 | 1,5 - 4,0 | >4,0 | 1.69 | 0.24 | <0.11 | <0.11 | 0.31 | <0.11 | 7.88 | <0.11 | 48 | 15.3 |

During the hydrocensus an oil dumping pit (by all accounts illegal) was identified in the Goudrand area, close to the Wit Potch Village, and in between an Eskom sub-station and a slimes dam (Figure 6-5).

Figure 6-5 Illegal oil dumping pit in Goudrand area

Natural dolomitic groundwater is essentially a Ca/Mg-bicarbonate type, alkaline and with an EC of less than 70 mS/m. However, the impacts of mining, industrialisation, waste disposal and agriculture have modified this natural water quality to a greater or lesser extent over most of the dolomitic areas. The favourable aquifer characteristics of high transmissivity, storativity and rapid recharge mean that the dolomite aquifers located downstream from the project area are vulnerable to contamination. Contamination is manifested by significant increases in concentration of Total Dissolved Solids, sulphate (acid mine drainage), sodium and chloride, and nitrate. Dissolved radionuclides are also a problem. Surface water and groundwater show very similar characteristics providing further evidence of their close relationship in dolomitic terrain.

With the discontinuing of mining activities water in the underground mines started to recover and rise to its previous levels. During the recovery the water comes into contact with sulphide minerals, thus becoming highly acidic. This water then reacts with other minerals, which in turn produce other pollutants in the water such as aluminium, lead, zinc, uranium, radium, as well as bismuth. Acid mine drainage (ADM) thus refers to the phenomenon whereby this highly contaminated, acidic water flows outwards onto the surface, often in very high dosages from abandoned mines.

AMD is currently the biggest environmental threat on the Witwatersrand, which occurs when ore and waste material, containing sulphides (pyrite) are exposed to water and oxygen. The most important sites for the creation of AMD are the discharge from open pits, discharge from underground mining shafts, as well as ore stockpiles. Since the formation of AMD is impacted by mineralogy, as well as other variables, the formation of AMD will differ from one area to another, which renders the predictive capacity about its formation - as well as occurrence - highly expensive and of ambiguous reliability.

As this contaminated groundwater rises to the surface, it becomes a part of the drinking water that is utilised by both the urban, as well as agricultural sector. Moreover, the intake of this water is highly hazardous to human health because of the presence of uranium in the water. Currently, AMD not only poses a hazard to South Africa's water supplies, but also to its major industrial centres.

## 6.5 Aquifer Hydraulic Properties

The key issues guiding management and use of aquifers are water level fluctuations and quality. The former is of importance in dolomitic areas where it impacts on geotechnical/ground stability, spring flows and ecology (wetlands). The latter is of importance in all areas of mining, agriculture and point sources, in terms of possible contamination of potable water supplies – surface and groundwater resources.

Dolomitic aquifers are unique in South Africa because of their very high transmissivity. This means that systems/compartments behave in a similar way to an individual production borehole. The total recharge to a compartment is thus theoretically available for abstraction instead of a percentage thereof.

The key hydraulic parameters that require quantification to enable the viability of abstraction schemes to be determined is transmissivity (T) and storage (S). These are also key parameters to define possible mine inflow. Much work has been carried out to try and determine methodologies and to assign values to these parameters in dolomitic areas (e.g. Bredenkemp et al, 1991). One of the key problems in this regard is the heterogeneity of the dolomite so that applying average figures across compartments is largely meaningless. In quartzite, shale and volcanic formations these parameters are easier to calculate and faults or dykes are often the preferred pathway and of limited extent, compared to dolomitic solution cavities.

*Transmissivity:*

Transmissivity (T) is very variable in the dolomite, ranging from nearly impervious to approximately 30 000 $m^3$/day/m. An interesting feature of the dolomite is the apparent increase in transmissivity towards the N-S dykes. This was noted in the Zuurbekom Compartment (SRK 1983, de Freitas and Wolmarans, 1978). In the Zuurbekom Compartment, T increased from an average 260 $m^3$/day/m to 25 000 $m^3$/day/m near the Gemsbokfontein Dyke.

Test pumping of exploration boreholes in the Klip River and Natalspruit Compartments

(Kafri et al 1986) gave highly variable results, with T ranging from tens of $m^3$/day/m to 1 000 to 2 000 $m^3$/day/m, with one anomalous value of 9 755 $m^3$/day/m.

The highly transmissive nature of the dolomite resulted in the original water table being very flat, with a very low gradient from one end of a compartment to the other. Solution cavities and fissures are likely to be enlarged with time by the rapid and continuous circulation of water from the surface into mine voids, thus increasing transmissivity and storage. This will induce hydraulic erosion of cavity/fracture infillings and chemical dissolution of the dolomite.

*Storage:*
Most groundwater potential occurs in the first 100 m and particularly, the first 30 m below the original water table. Various estimates for storage or porosity have been put forward.

Because of the nature of weathered or fractured aquifers, these variations cannot be assigned to specific areas or zones and conditions vary greatly over short distances. Transmissivity and S values obtained from test pumping can be particularly site specific and misleading. Water balances or numerical models offer a better method of obtaining representative S values.

*Recharge:*
Recharge is defined as the process by which water is added to the zone of saturation of an aquifer. It is considered that recharge to the Witwatersrand formation aquifers may be 1% to 2% of MAP (mean annual precipitation).

Recharge estimates for the dolomite generally fall in the 10% to 15% of MAP range, with some values in the 20% to 50% range. The latter often relates to areas characterised by sinkholes and subsidence development, lowering of water levels and widening of conduits that may lead to an enhanced recharge potential (DWAF, 2006).

There are several routes by which precipitation recharges groundwater in the study area. In addition to direct recharge in open veld, parks and gardens, localized recharge often occurs along edges of paths and roads, where no formal storm water drainage exists. Land covered by an impermeable surface decrease recharge.

Water supply infrastructure in urban settings results in large volumes of water circulating below the surface; together with subsequent disposal of most of this water in sewers or on-site facilities such as septic tanks. Water mains are prone to leakage because they are constantly pressurized. Rates of leakage of 20% to 25% are common (Lerner, 2002). This water is available for recharge and sometimes is equal to or exceeds the recharge derived from direct precipitation. This form of recharge unfortunately also contributes to aquifer contamination impacts.

# 7 Aquifer Characterisation

Aquifer characterisation is based on the information presented thus far, and guidelines and maps provided by the DWS.

### 7.1 Groundwater Vulnerability

Groundwater vulnerability indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Based on the aquifer vulnerability map published by the Department of Water and Sanitation (DWS) in July 2013 the circular dolomitic outcrop in the area is classified as a most vulnerable aquifer region, which is vulnerable to pollutants except those strongly absorbed or readily transformed in many pollution scenarios (DWS, July 2013). The Witwatersrand and Ventersdorp Formations are least vulnerable.

### 7.2 Aquifer Classification

Based on the aquifer classification map published by the DWS in August 2012 the aquifer classification system defines the dolomite in the area as a major aquifer region, which is a high-yielding system of good water quality. The Witwatersrand and Ventersdorp systems are classified as minor aquifers.

### 7.3 Aquifer Susceptibility

Aquifer susceptibility is a qualitative measure of the relative ease with which a groundwater body can potentially be contaminated by anthropogenic activities and includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification. Based on the classification above the Witwatersrand and Ventersdorp formations have a low susceptibility to contamination. The dolomite in the circular outcrop and towards the south (downgradient) is highly susceptible to contamination.

## 8 The Model Development

### 8.1 Modelling protocol and guidelines

The numerical modelling follows a series of processes to acquire an acceptable fit during calibration. This enables the model to be used for any predictive scenario, in this case, water supply and impact simulation. The data obtained, historical and current were reviewed as input data to:

1. Construct and populate a numerical model with adequately defined and defendable model boundaries.
2. Complete a steady state calibration of the model by adjusting the hydraulic conductivity values and recharge until an acceptable fit was obtained. An acceptable fit is classified as when the Root Mean Square Error is less than 10% of the difference of the calibrated head distribution in the model domain.
3. The calibrated model is then used for predictive modelling and simulation of various scenarios to evaluate relevant simulated impacts associated with the proposed mine development.

### 8.2 Model Layers

The numerical model was constructed as a 3D model to simulate the potential impact on the receiving environment associated with the various open pits and the proposed waste rock dumps (WRDs) and underground mining operations.

The water levels recorded during the hydrocensus are located at distances in excess of 1 000 m from the Rugby Club Open Pit, 1900 m and 3 200 m away from 11 Shaft and Kimberley East Open Pits respectively (i.e. WitBH6). WitBH4 is located 500 m east of Roodepoort Open Pit and WitBH1 is located 1 150 m east of Mona Lisa open pit. Water levels closer to the open pits are required i.e. drilling of a monitoring borehole prior to mining at each open pit to assess and confirm the hydraulic head at each mining area.

The waste rock dumps are located on the southern edges of the open pits, mostly down gradient of the open pits. Based on the proposed mining depths and calibrated hydraulic gradients, the following summary of proposed mining depths, pit bottoms and foreseen groundwater interaction is provided in Table 8-1 below.

Table 8-1 Open pit elevation summary

| Open Pit | Mining Depth (m) | Approximate Surface Elevation (mamsl) | Calibrated Hydraulic Head (mamsl) | | Approximate Pit Bottom (mamsl) | Possible Water Interception |
|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | | |
| Kimberley East | 20 - 30 | 1700 | 1665 | 1677 | 1670 | Yes |
| 11 Shaft | 20 - 30 | 1700 | 1680 | 1694 | 1670 | Yes |
| Rugby Club | 7 - 10 | 1713 | 1692 | 1695 | 1703 | No |
| Mona Lisa | 20 - 30 | 1710 | 1677 | 1696 | 1680 | Yes |
| Roodepoort | 7 - 10 | 1740 | 1704 | 1725 | 1730 | No |

Although the detail provided is a qualification of the current regime, three of the five open pits can expect to intercept groundwater during the mining operations. This is purely based on the simulated/calibrated hydraulic heads of the numerical groundwater flow model and the expected mining depths. Boreholes to be located at each of the open pits should be drilled before mining commence to assess the groundwater level at the open pits.

## 8.3 Model representation and mesh

Feflow® was used as the preferred modelling package for the proposed mine dewatering scenarios using finite elements. The numerical mesh is shown in Figure 8-3 and the geological input and calibration boreholes used in Figure 8-5. The mesh was discretised such that the number of obtuse angles i.e. to ensure that violating Delauney criteria is less than 5% - assisting in mathematical and numerical computing and stability of the model.

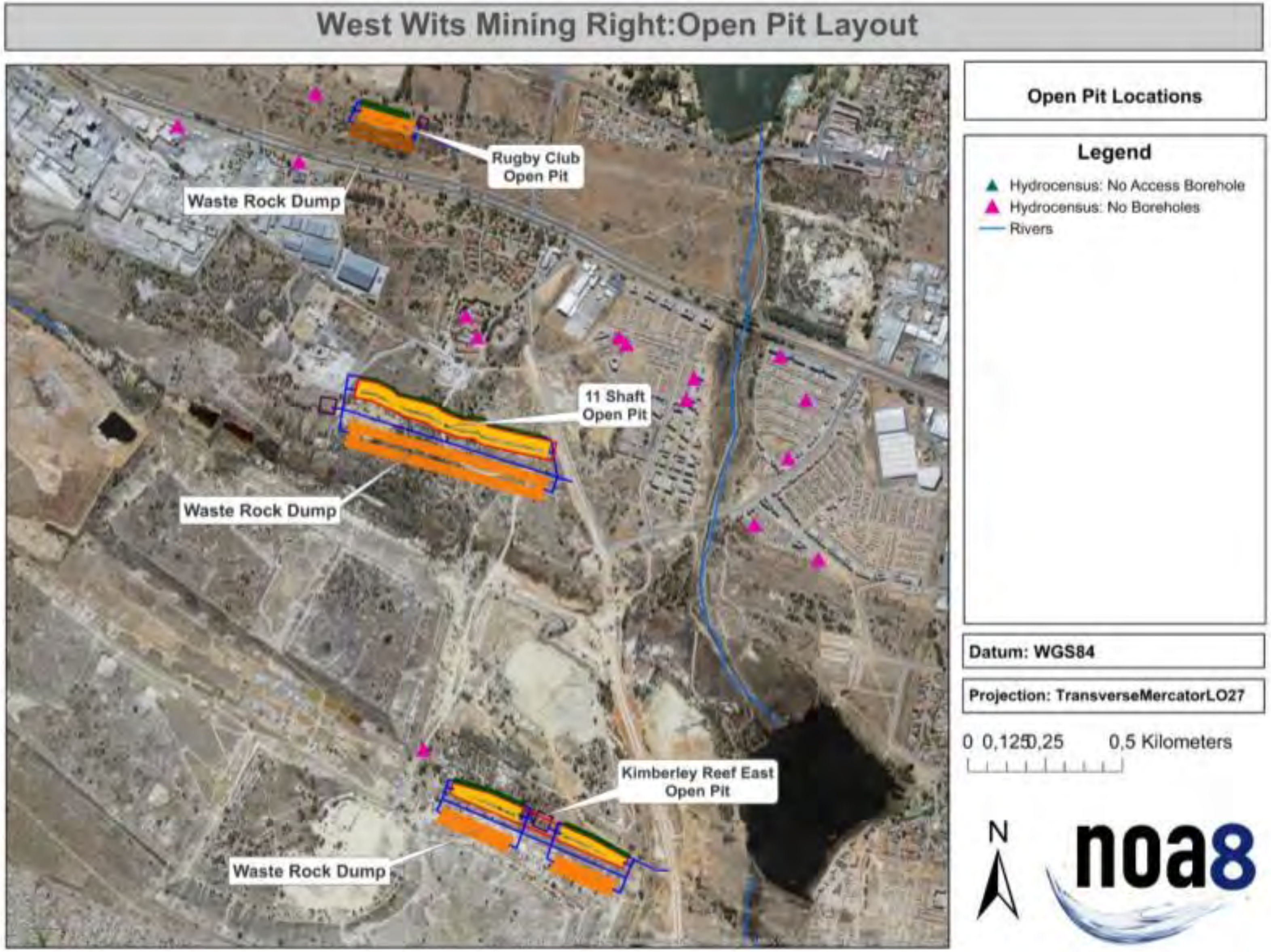


Figure 8-1 Kimberley Reef East, 11 Shaft and Rugby Club open pit mine layouts and recorded hydrocensus locations

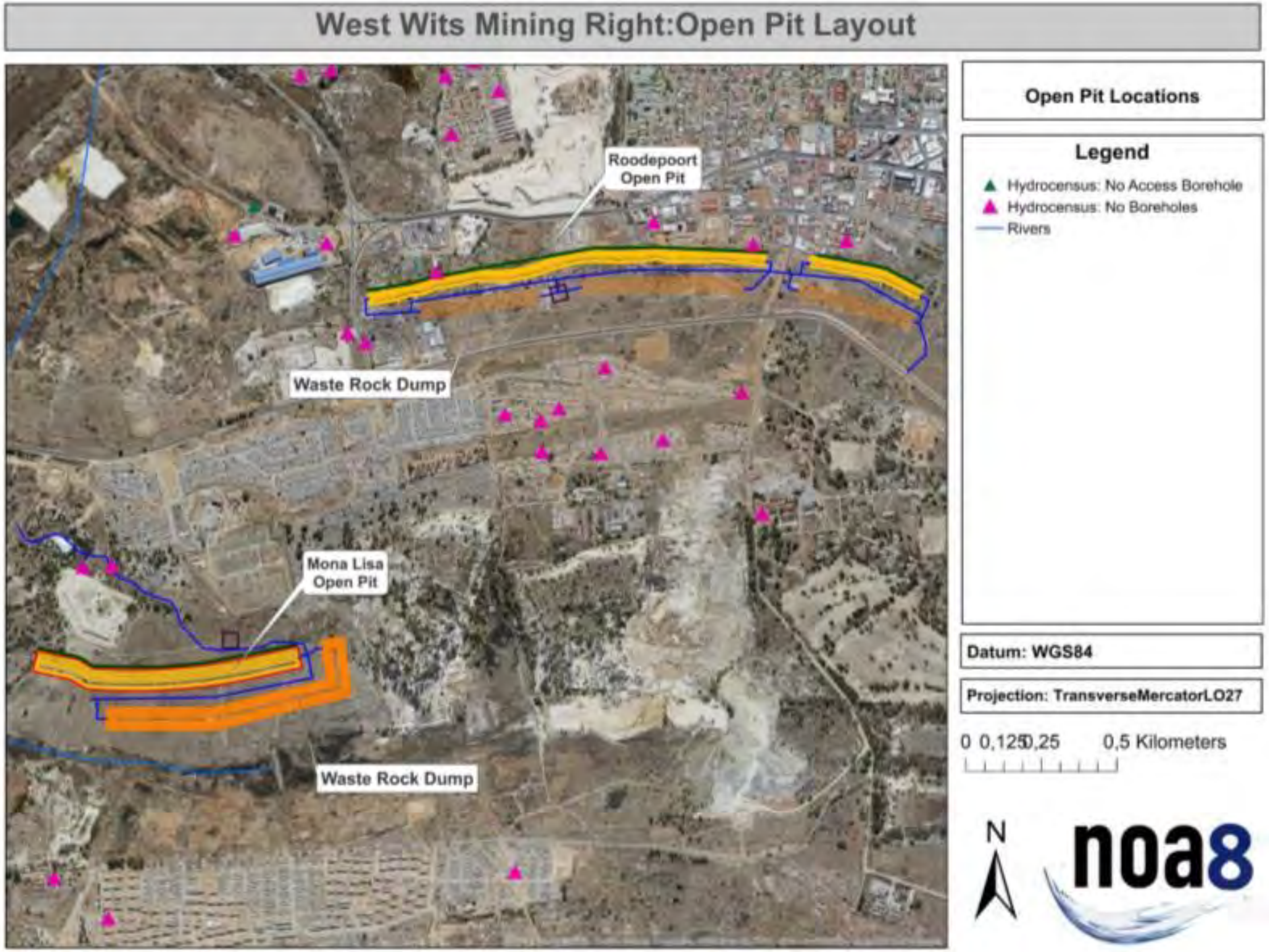


Figure 8-2 Mona Lisa and Roodepoort open pit mine layouts and recorded hydrocensus locations

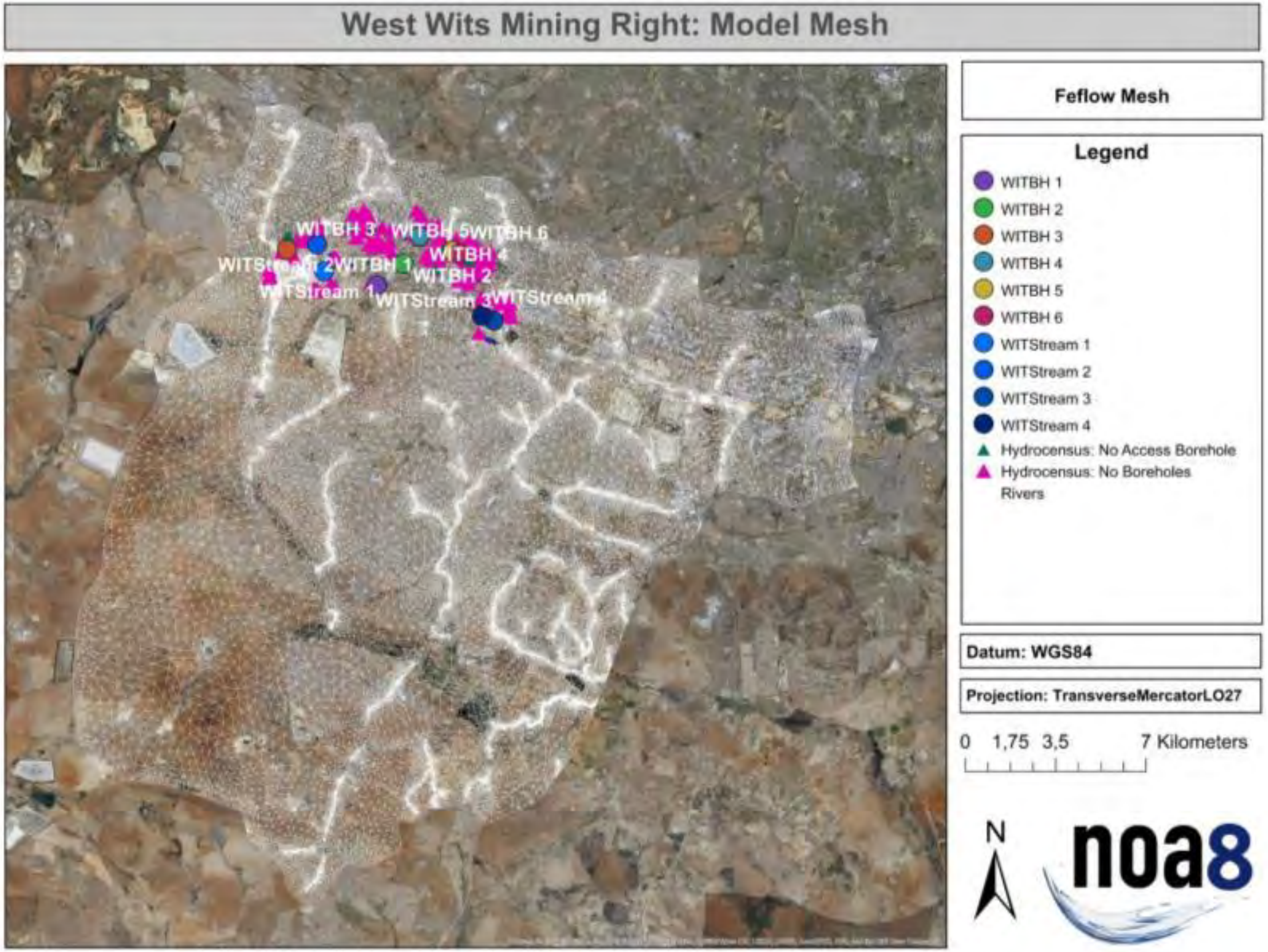


Figure 8-3 Model mesh and boundaries - regional

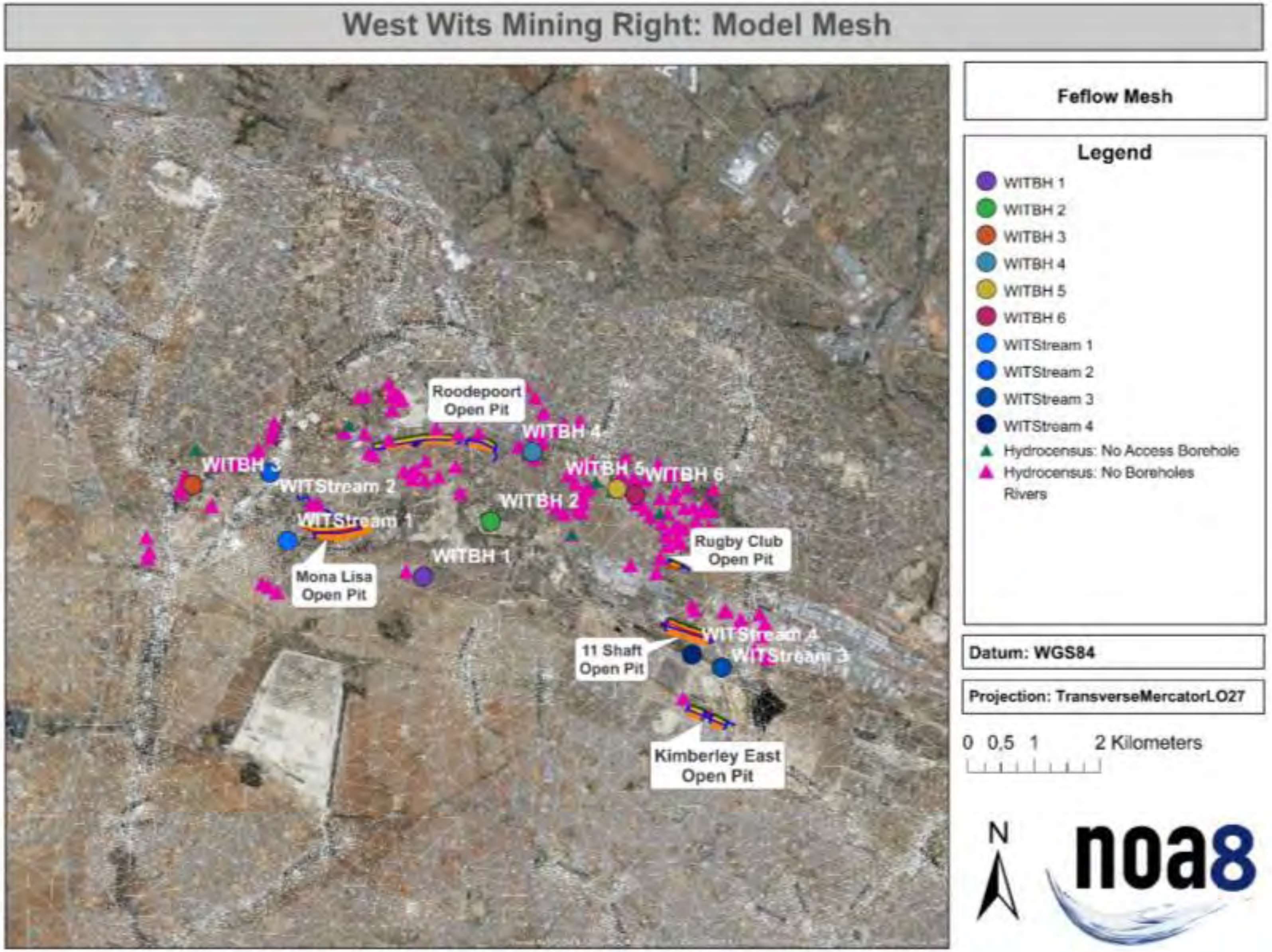


Figure 8-4 Model mesh and boundaries - local

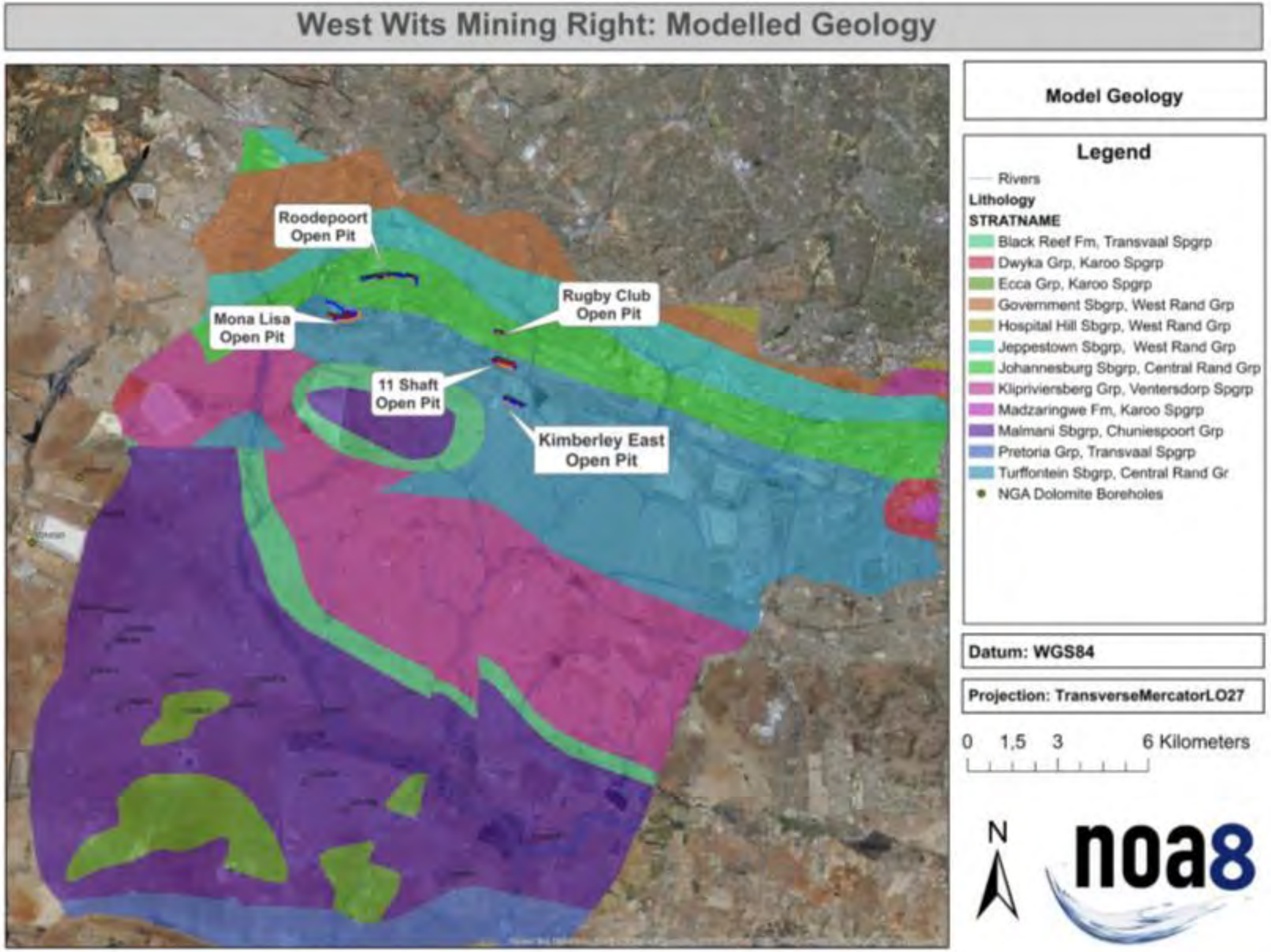


Figure 8-5 Modelled geology

Hydrogeological boundaries are detailed as:

1. Vertical and spatial distribution of the hydro stratigraphic units
2. The piezometry (head contours from measured water levels) indicated a natural groundwater flow from the topographical high in the north towards the south and south east.
3. The model boundaries are defined by no-flow boundaries coinciding with the boundaries of the quaternary catchment C22A.
4. Internal partial barrier boundaries are defined by geological features explicitly added to the modelling domain.

# 9 Model Calibration

## 9.1 Simulation scenarios

Various simulations are required to use the numerical flow model as a tool in water supply and potential impact assessments. The recent and historical data is used to calibrate the model, always an iterative process. The calibration process was completed in steady state (time independent and only hydraulic conductivity and recharge parameters adjusted).

The following scenarios were simulated and discussed next:

5. Steady state calibration: Status Quo groundwater flow
6. Predictive scenarios:
    a. Mine dewatering from Kimberley East, 11 Shaft, Rugby Club, Mona Lisa and Roodepoort open pit and mass transport associated with the WRD’s.
    b. Underground mine dewatering simulations for Bird Reef Central and Kimberley Reef East underground mine workings
    c. Post operation mass transport: 1 year and 10 years.

## 9.2 Steady state calibration

The objective of the steady state model calibration was to reproduce measured water levels at observed heads and generated piezometry. In total, 19 observation points were used for the initial steady state model calibration i.e. four recorded during the 2018 hydrocensus and 15 boreholes sourced from the DWS database for the dolomitic monitoring plan. The dolomite boreholes are located in excess of 10 km south of the proposed open pit mining areas and underground mine workings and were omitted from the current calibration discussion. The calibration focused on the four recorded water levels within the project area.

Table 9-1 indicates the measured and modelled heads and the calibration error. A bar chart diagram of the observed versus modelled heads is shown in Figure 9-1.

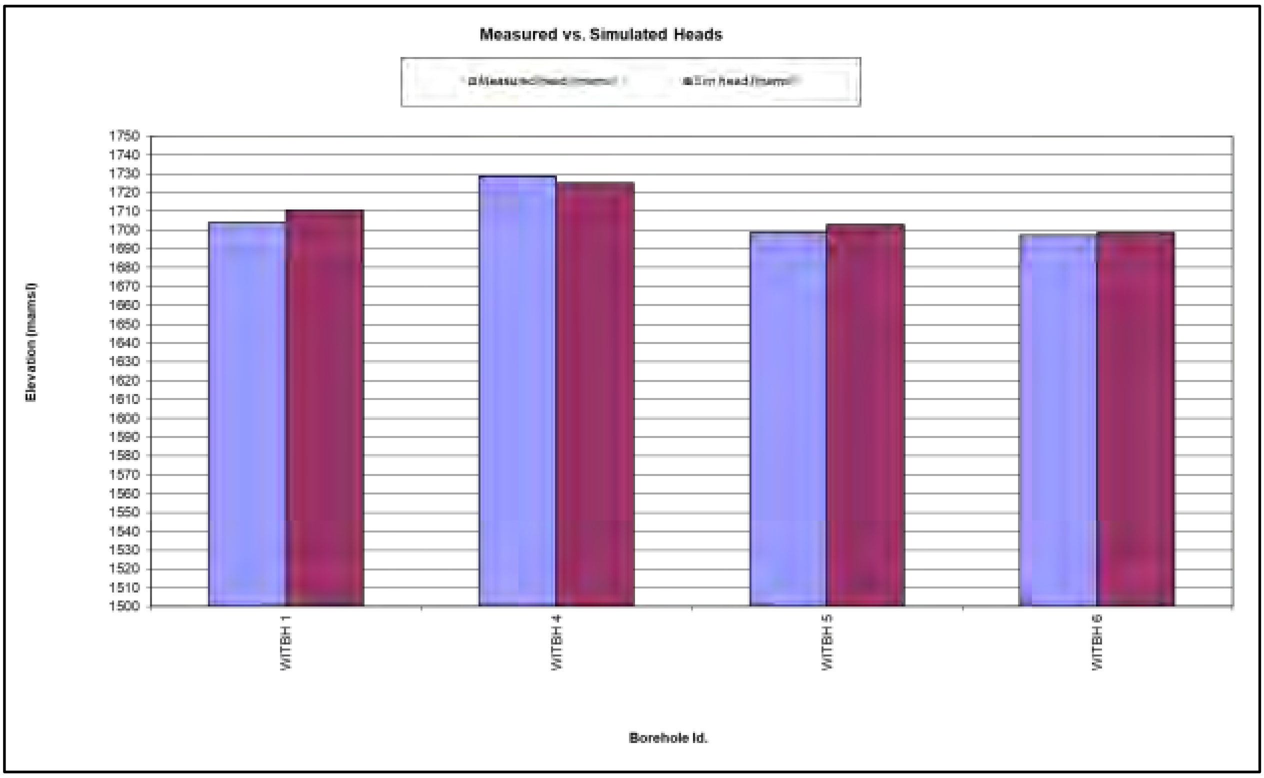


Figure 9-1 Bar chart diagram of observed and modelled hydraulic heads

The minimum calibration error is 1.48 m and the maximum error 6.97m. General standard practice for calibration evaluation is to obtain a Root Mean Square Error (RMSE) of such a value, that when compared with the head difference measured in the modelled area, should not exceed 5%. In this case, the RMSE correlates to approximately <5% measured against the water levels change over the model domain.

The groundwater flow model should be viewed as/at a conceptual level and qualified rather than calibrated due to the limited number of groundwater sites available to populate the numerical groundwater flow model, and the absences of local groundwater sites at the proposed open pit mining areas and underground mine workings. The groundwater flow model should be updated once more data becomes available.

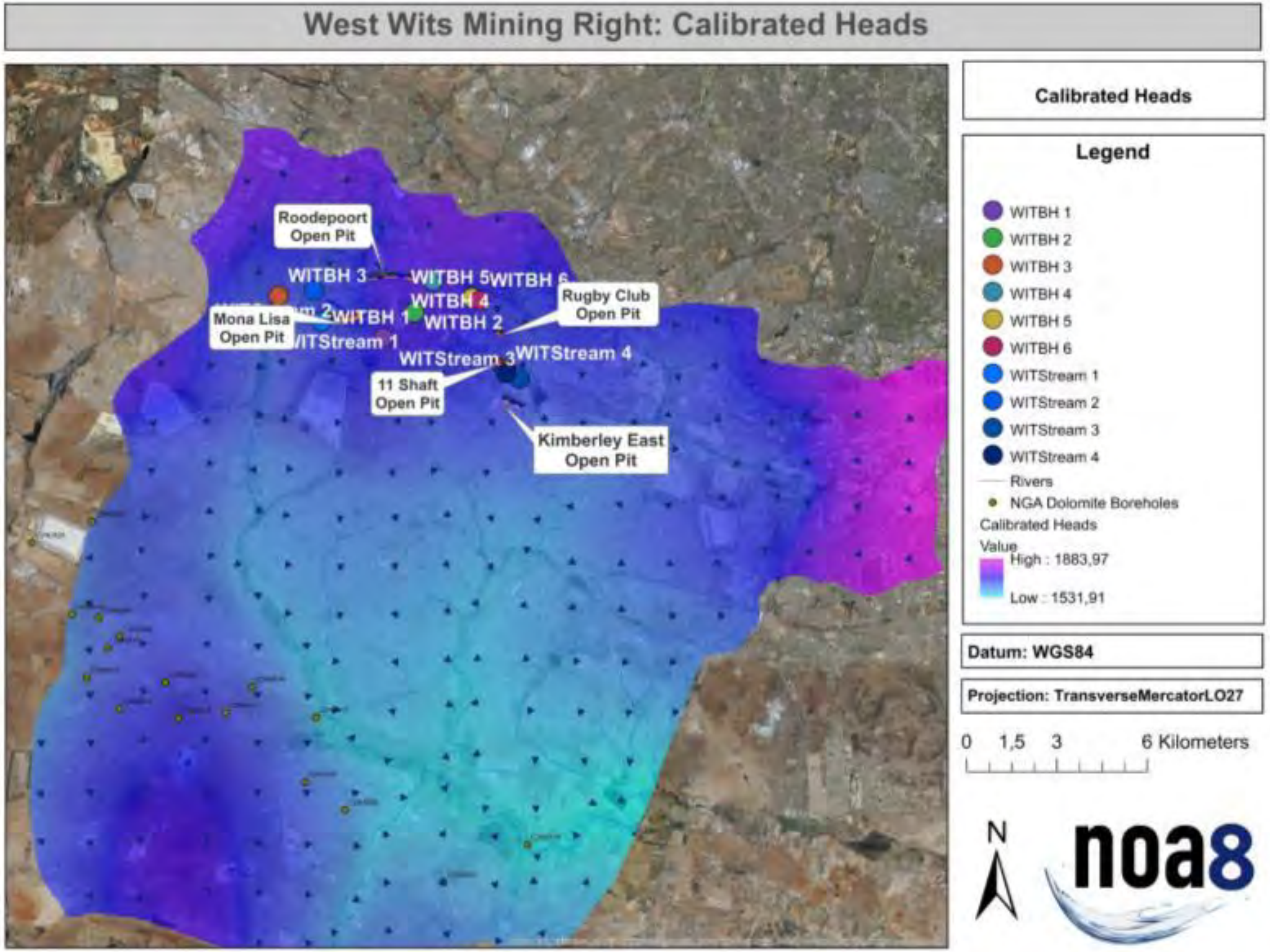


Figure 9-2 Steady state calibrated groundwater levels

Table 9-1 Steady state modelled heads and calibration error

| Site No. | X | Y | Z | BH | Water Level (mbcl) | Measured head (mamsl) | Sim head (mamsl) | Mean Absolute Error (m) MAE | Mean Error (m) ME | Root Mean Square Error (m) RMS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 85653 | -2897413 | 1740.20 | WITBH 1 | 36.22 | 1703.99 | 1710.75 | 6.76 | -6.76 | 45.75 |
| 2 | 87309 | -2895527 | 1740.74 | WITBH 4 | 11.90 | 1728.84 | 1725.30 | 3.54 | 3.54 | 12.50 |
| 3 | 88589 | -2896086 | 1706.50 | WITBH 5 | 7.70 | 1698.80 | 1702.95 | 4.15 | -4.15 | 17.24 |
| 4 | 88861 | -2896177 | 1701.70 | WITBH 6 | 4.46 | 1697.24 | 1698.72 | 1.48 | -1.48 | 2.19 |
| | | | | | Avg | 1707.22 | 1709.43 | 3.98 | -2.21 | 19.42 |
| | | | | | Min | 1697.24 | 1698.72 | 1.48 | -6.76 | 2.19 |
| | | | | | Max | 1728.84 | 1725.30 | 6.76 | 3.54 | 45.75 |
| | | | | | Correl | 0.97 | | | | |

## 9.3 Steady state model calibration discussion

### 9.3.1 Model uncertainties

Model uncertainties arise from uncertainties in the calibrated aquifer parameters of hydraulic conductivity, aquifer external and internal boundary conditions recharge parameters, initial head conditions and other external stresses.

Uncertainties in the steady state model are:

1. Absence of consolidated long-term water level monitoring data to evaluate long-term water level changes in the area prior to mining, during historical mining and current status for the entire spread of water level points available.
2. Continued spread and distribution of recent recorded water level data across the project area. Before any mining commences, water monitoring points should be installed, and the model updated with the latest results to update the water management plan.
3. Spatial distribution of the recharge rate and aquifer hydraulic parameters is not currently well known at the various open pit mining areas. Recharge rates used between 17 and 35 mm/a (2 – 5% of MAP) for the local project area aquifers correlates well with analogue studies of the area (Figure 9-3).
4. The transmissivity applied to the regional model during the calibration process are indicated in Figure 9-4 and vary between 2.5 – 5 $m^2/d$.

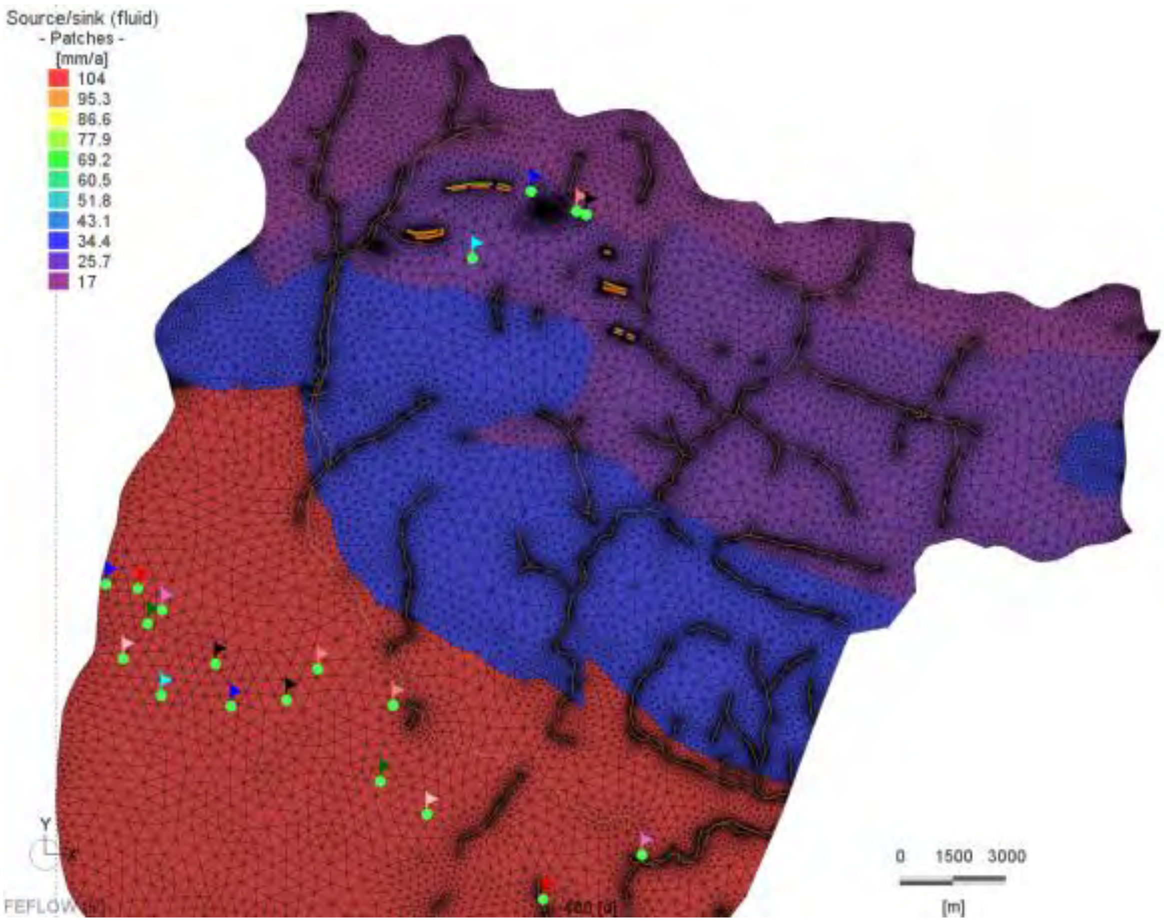

Figure 9-3 Recharge distribution used in model calibration

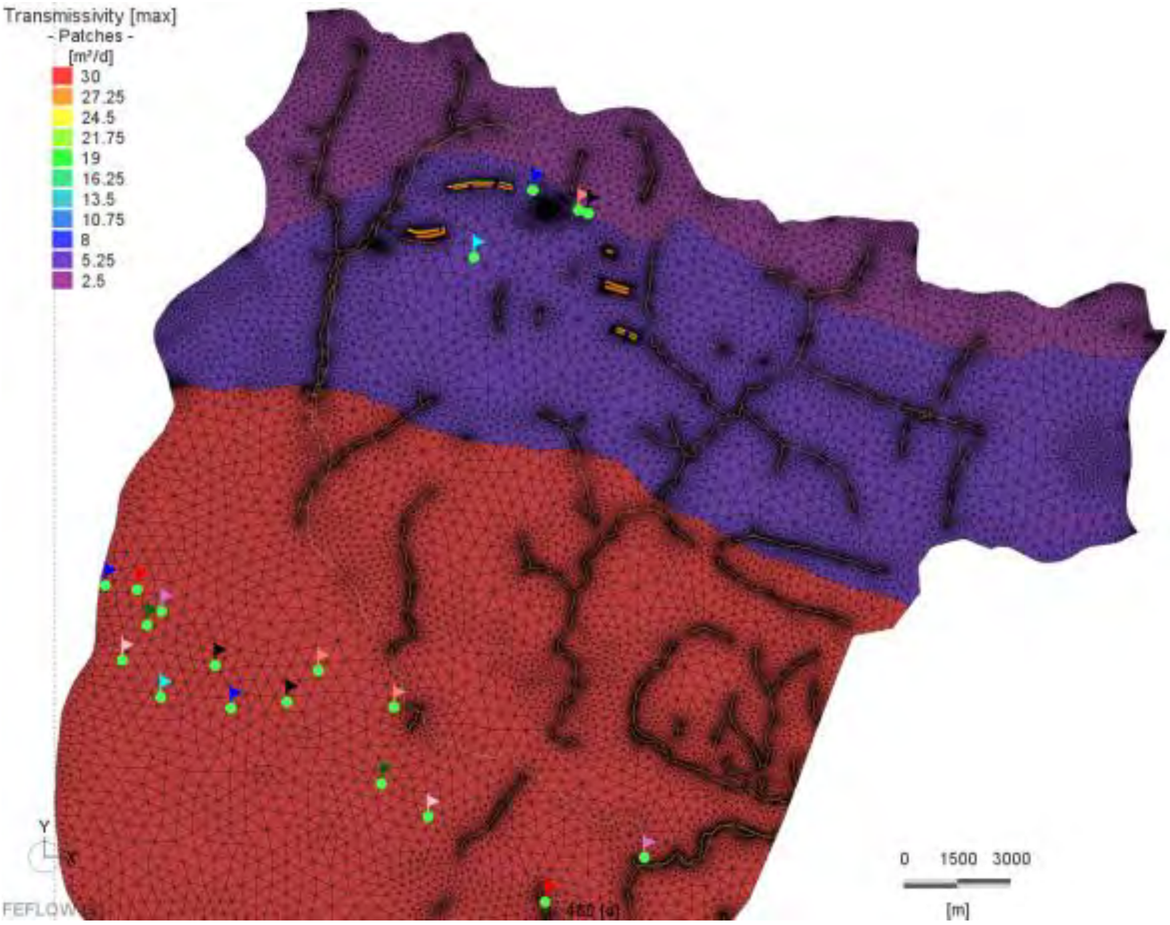


Figure 9-4 Transmissity distribution obtained during the steady state calibration process for the West Wits Project area

5. The biggest uncertainty arises from the modelled storativity values applied for the transient simulations. The values used is an estimation, however, the water balances assist in verifying the data used. The values used as input into the model correlates well with similar values indicated in Spitz and Moreno, 1996.

9.3.2 Assumptions and limitations

1. The geology was based on the 1:250 000 published geological map as well as 1:50 000 topographical maps.
2. ArcGIS online aerial imagery are used in the layout of the various maps compiled for the current report. The imagery might be outdated and are used for reference only.
3. Regional groundwater usage i.e. private and neighbouring mine use. This abstraction may influence the current calibration and should be quantified in the future and updated in the groundwater flow model.

4. The model is used for decision making and should be applied accordingly. Modelled impacts may vary at any point and on-going monitoring is required to actively manage the proposed mining activities and possible impacts.
5. The groundwater flow model should be updated as new data becomes available.

# 10 Predictive modelling

## 10.1 Objective of predictive modelling

The predictive model in this case simulates the proposed mining of the five open pits for a period of up to 12 months and associated mass transport possibly originating from the waste rock dumps during mining and rehabilitation.

Post operational mining, the WRD is reworked and the open pit backfilled with the waste material.

Important input to the transient mine dewatering and mass transport model:

1. The open pits vary between 10 and 30 m deep (Table 8-1). The expected pit depth is such that possible groundwater inflow is expected at three of the five open pits. Monitoring boreholes should be drilled before mining commence to assist in ongoing monitoring and to establish the groundwater levels in close proximity at each of the open pits.
2. The geochemical nature of the waste rock was assessed and reported on in detail in Geochemical Assessment for the proposed West Wits Mining Project, R N Hansen. 02 May 2019. The following key conclusions from the report was taken into account with the mass transport simulations for the Waste Rock Dump:
    a. Acid Mine Drainage: The acid base accounting and geochemical modelling have indicated that due to the absence of iron sulphide minerals the risk of the development of AMD conditions in the waste rock environment is negligible.
    b. Leaching of metal(loid) contaminants: The leach test indicated that all by three potential contaminants are below detection in the waste rock leachate and the three that are above detection have concentrations significantly below the regulatory values. The geochemical model, which was developed to evaluate the leach test, also shows that the risk of leaching of contaminants, especially the metalloid arsenic, from the waste rock is negligible. This is also due to the absence of iron sulphide as well as the high stability of the minerals comprising the waste rock at the mining conditions.
    c. Based on this a Class D barrier system (stripping topsoil and base preparation) was recommended by the geochemistry specialist. This has been taking into account in this study.
    d. Mitigation: Due to the negligible risk of the formation of AMD conditions as well as the negligible risk of the leaching of contaminants from the waste rock material, no mitigation measures are required for the waste rock material.
3. For the mass transport simulations, due to the absence of any possible leachate, a conceptual mass transport simulation was conducted for management purposes and assist the applicant in monitoring the possible influence of the WRD during operations and the backfilled open pit during post operations. A conceptual background value of 5 mg/L was assigned to the host rock, and a potential leachate from the WRD of 100 mg/L (i.e. 100% of a possible certain mass originating from the

WRD and open pit post closure). This simulation intends to assist the applicant in continuing the monitoring protocol suggested. Please note that the mass migration simulation is for management purposes and the chosen parameters (5% for background and 100% for source) simulate worst case scenario i.e. although the source term would remain 100%, the background value may alter to 10, 20 or 50%, influencing the mass migration potential.

The following key notes to take cognisance of with regards to the mine dewatering and potential mass transport associated with the open pits:

1. Ongoing monitoring is key to any mitigation required during and post operation.
2. Should the monitoring data indicate any potential impact due to the proposed mining activities, swift decision and mitigation protocols can be made accordingly – to minimise any possible impact on potential receptors.
3. Although the data and simulations indicate that the impact will be little to negligible, it should still be monitored pre, during and post mining activities.

The operational modelling simulations was conducted for 90 - 360 days (~3 - 12 months) and the post operational scenarios to assess the potential mass migration from the WRD (potential source deposited during mining) and backfilled open pit for 1 year and 10 years respectively.

## 10.2 Surface mine dewatering and mass transport: Operational

The open pits were included in the numerical model as designed i.e. depth versus proposed durations of mining. The mining sequence was activated for the number of days for each open pit and the simulated impact assessed.

The potential dewatering volumes associated with the mining at the five open pits with time is provided in Figure 10-1 - Figure 10-5. The simulated dewatering volumes provided i.e. both upper and lower inflows are an indication of volumes that can be possibly intercepted. However, evaporation plays a major role as a sink, and storm water run-off could contribute to in-pit pumping requirements.

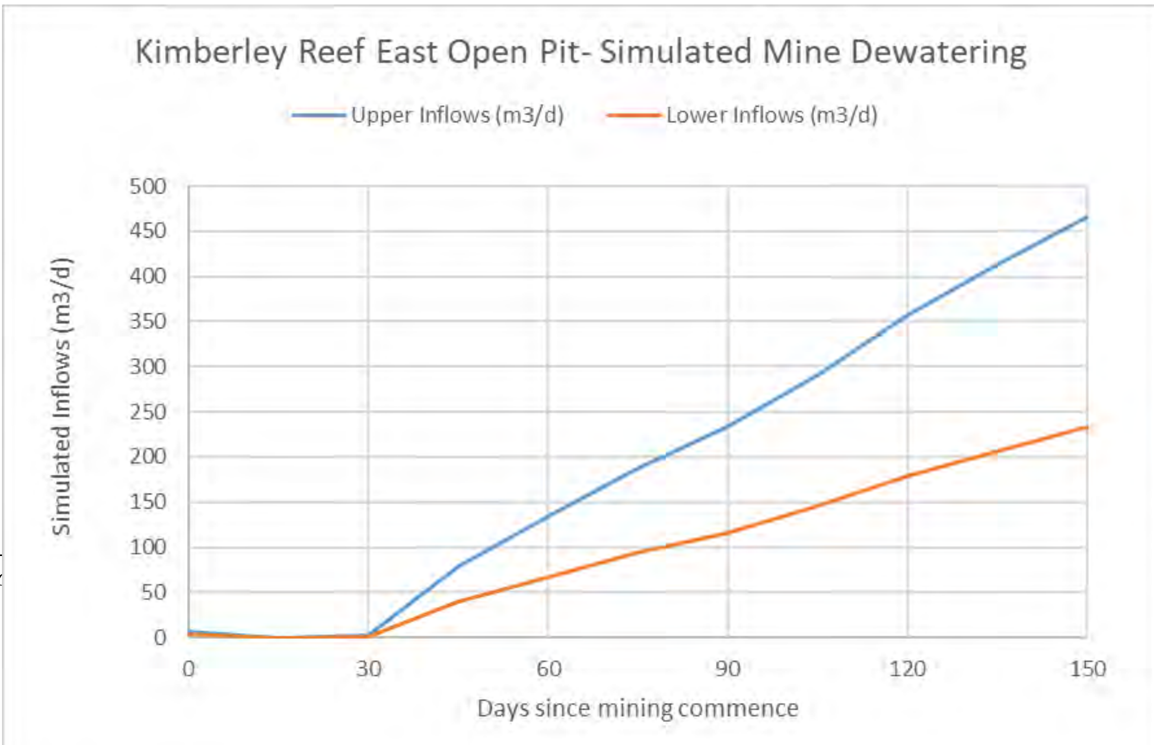

Figure 10-1 Simulated inflows reporting to the Kimberley Reef East open pit during mining

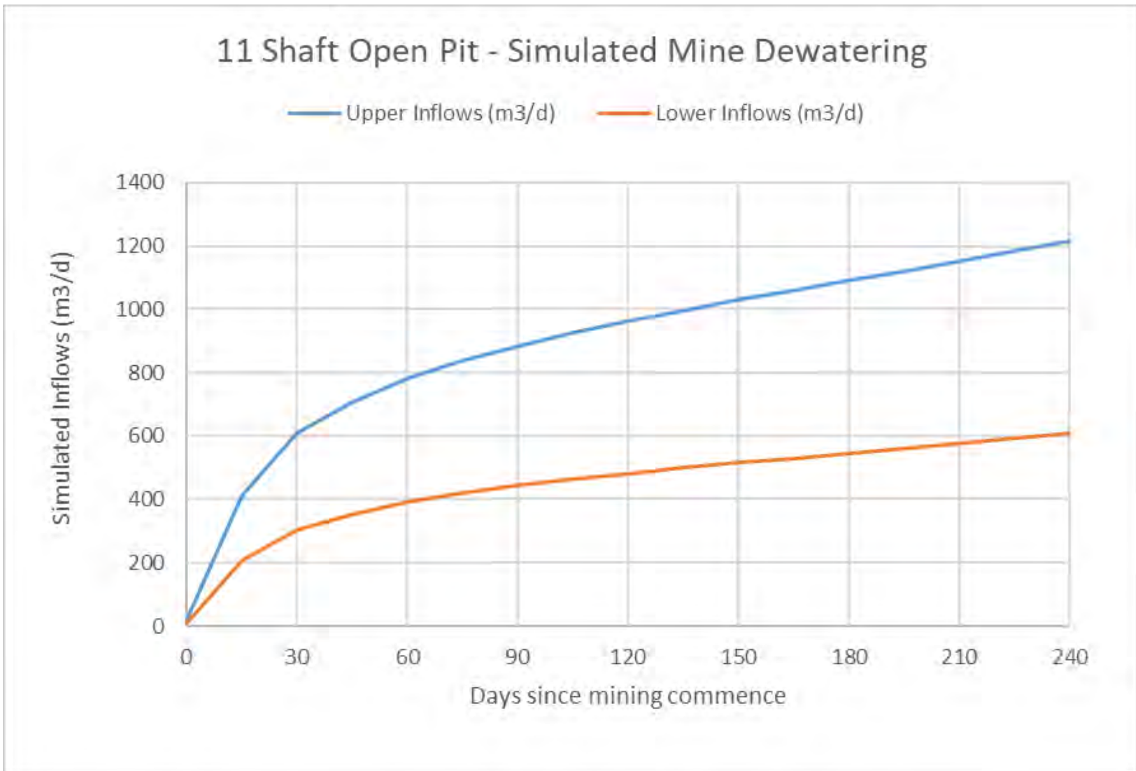


Figure 10-2 Simulated inflows reporting to the 11 Shaft open pit during mining

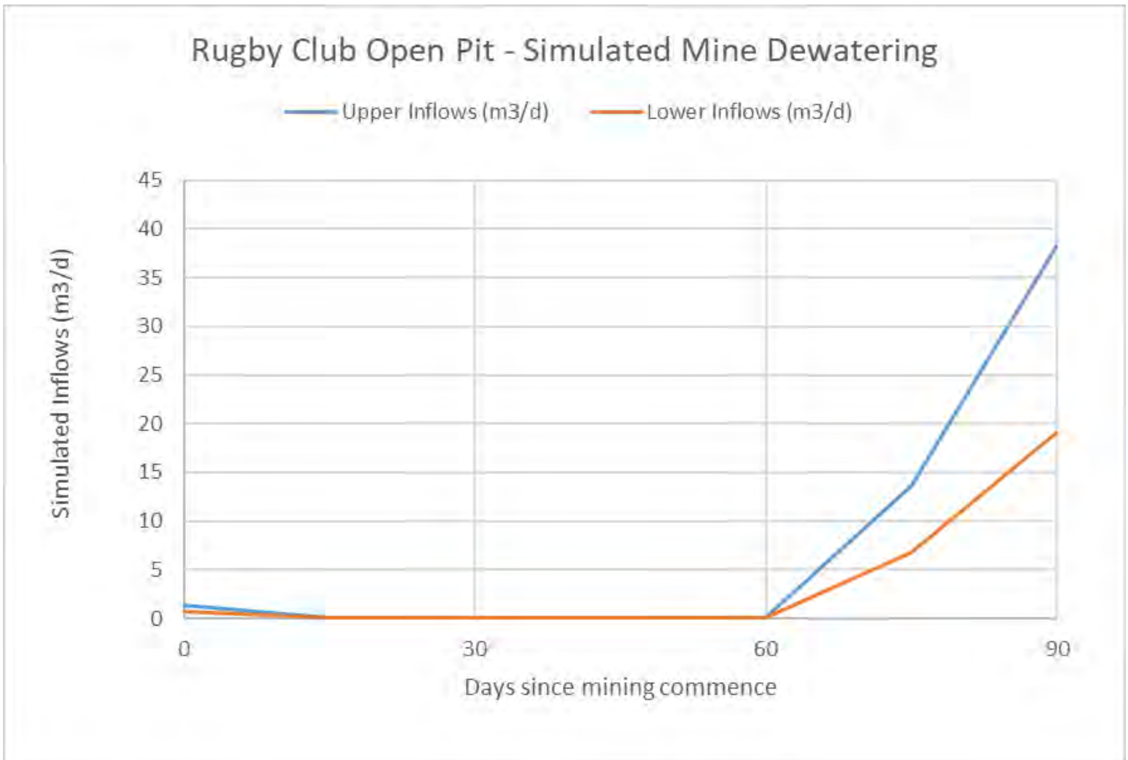


Figure 10-3 Simulated inflows reporting to the Rugby Club open pit during mining

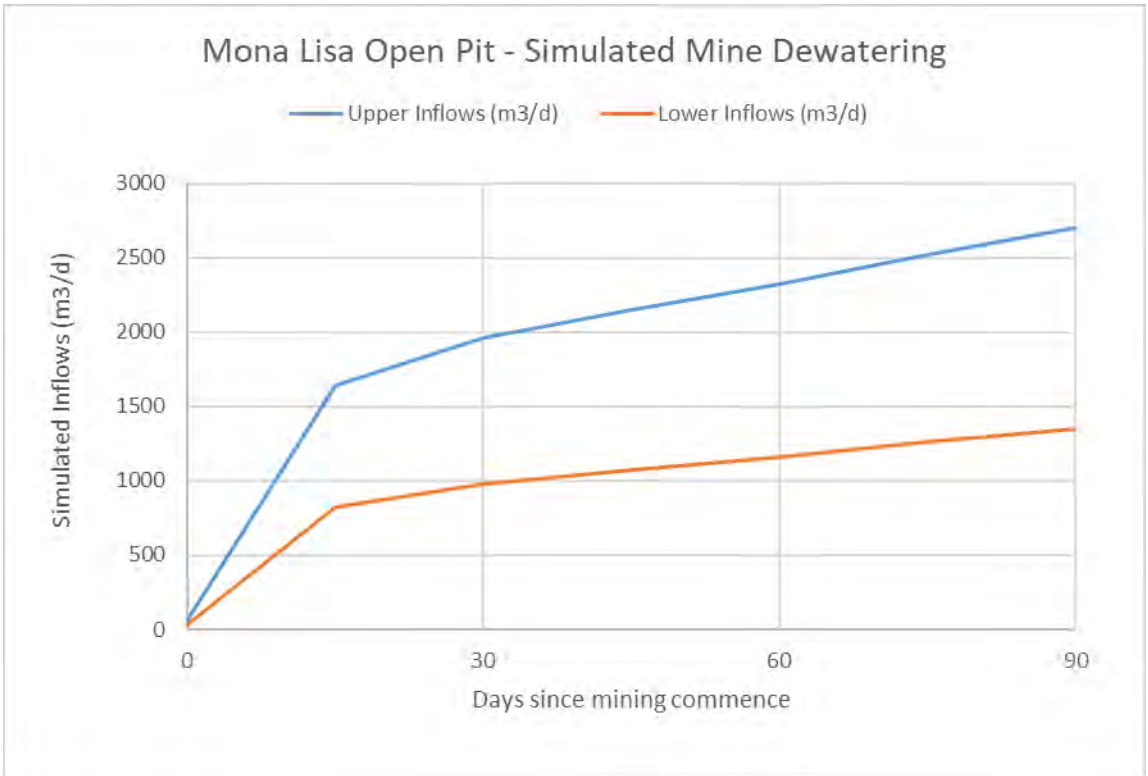


Figure 10-4 Simulated inflows reporting to the Mona Lisa open pit during mining

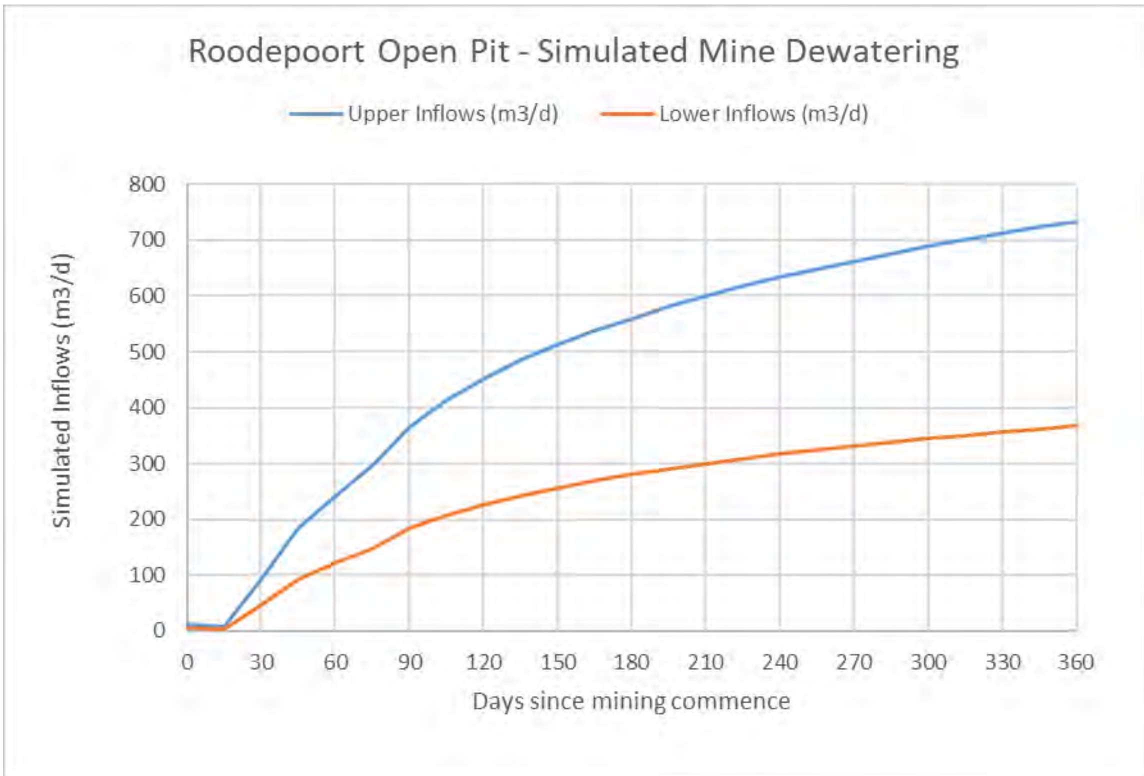


Figure 10-5 Simulated inflows reporting to the Roodepoort open pit during mining

The dewatering rates simulated during the numerical groundwater flow model is not subjected to evaporation, hence an envelope of inflows provided for management purposes. The simulated dewatering rates are as follows:

1. Kimberley Reef East: 225 – 466 $m^3$/d
2. 11 Shaft: 600 – 1215 $m^3$/d
3. Rugby Club: < 50 $m^3$/d
4. Mona Lisa: 1350 – 2700 $m^3$/d
5. Roodepoort: 370 – 730 $m^3$/d

The proximity of the Mona Lisa open pit to the Klipspruit tributary to the south and the Klipspruit River to the west influences the potential dewatering volumes. The simulated hydraulic gradient is shallower in this area due to the water courses. Additional drilling is required at Mona Lisa to establish the groundwater level to increase the accuracy of the expected dewatering rates. Once drilling is completed, an aquifer test should be performed and the water sampled should be compared to the Klipspruit River water to establish a link, or absence there-of, between the potential dewatering at Mona Lisa and the Klipspruit River. Until proven otherwise, the assumption is made that the dewatered volume simulated in the numerical flow model is derived from shallow groundwater flow that contribute to baseflow.

It is possible that the zero water accumulates in the open pit, especially during the dry seasons.

The simulated Zone of Influence (ZOI) and potential mass migration from the waste rock dumps (WRD) is provided in Figure to Figure 10-15. At least one monitoring point should be installed at each of the proposed open pits with the proposed points as follows:

1. One monitoring borehole south of each WRD
2. One monitoring borehole to the west of the Mona Lisa open pit, between the open pit and the Kliprivier.

The monitoring points should confirm the geochemical results i.e. no leachate potential from the waste and no AMD formation. The monitoring should commence prior to any mining activities and continue in post operational phase during rehabilitation of the WRD and the open pit, at least two years post operation.

## 10.3 Water balance

The water balances associated with the simulated scenarios is provided in Table 10-1.

1. Steady State Qualification
    a. Recharge from precipitation accounts for 86 233 $m^3$/d over the entire modelled domain, with in and outflows along rivers/drainages accounting for 6 151 $m^3$/d and 92 384 $m^3$/d respectively.
    b. No additional flow components during steady state calibration
2. Operational Phase
    a. Potential cumulative recharge of 5 700 $m^3$/d on all of the WRD footprints due to precipitation and increased recharge coefficients. This does not occur simultaneously as the mining occurs in sequence.
    b. Peak cumulative dewatering simulated at 2 700 $m^3$/d at Mona Lisa during the open pit mining. The dewatering rates should still be subjected to evaporation

which will decrease the volumes substantially. Drilling of characterisation boreholes prior to mining should be conducted and the model should be updated accordingly.

3. Post Operational Phase
   a. The only additional flow component is the increased recharge simulated on the rehabilitated open pit footprints of 100 mm/a (approximately 15% of MAP). This amounts to approximately 10 - 30 $m^3/d$.

Table 10-1 Water balance

| Component | Steady State | | Operational | | Post Operational | |
|---|---|---|---|---|---|---|
| | In ($m^3/d$) | Out ($m^3/d$) | In ($m^3/d$) | Out ($m^3/d$) | In ($m^3/d$) | Out ($m^3/d$) |
| Recharge (Precipitation) | 86233 | | 86233 | | 86234 | |
| Distributed Sinks (Rivers/Drainages) | 6151 | -92384 | 6151 | -92273 | 6151 | -92386 |
| Open Pit Dewatering | | | | | | 0 |
| Kimberley East | | 0 | | -466 | | |
| 11 Shaft | | 0 | | -1215 | | |
| Rugby Club | | 0 | | -50 | | |
| Mona Lisa | | 0 | | -2700 | | |
| Roodepoort | | 0 | | -730 | | |
| Waste Rock Dump | 0 | | 5700 | | | 0 |
| Back Filled Open Pit Recharge | 0 | | 0 | | 10 | |
| Decanting | | 0 | | 0 | | 0 |
| Storage | 0 | 0 | 101 | -755 | 0 | 0 |
| Balance (In/Out) | 92384 | 0 | 98185 | -98189 | 92395 | -92386 |
| Error (%) | 0.00% | | 0.00% | | 0.01% | |

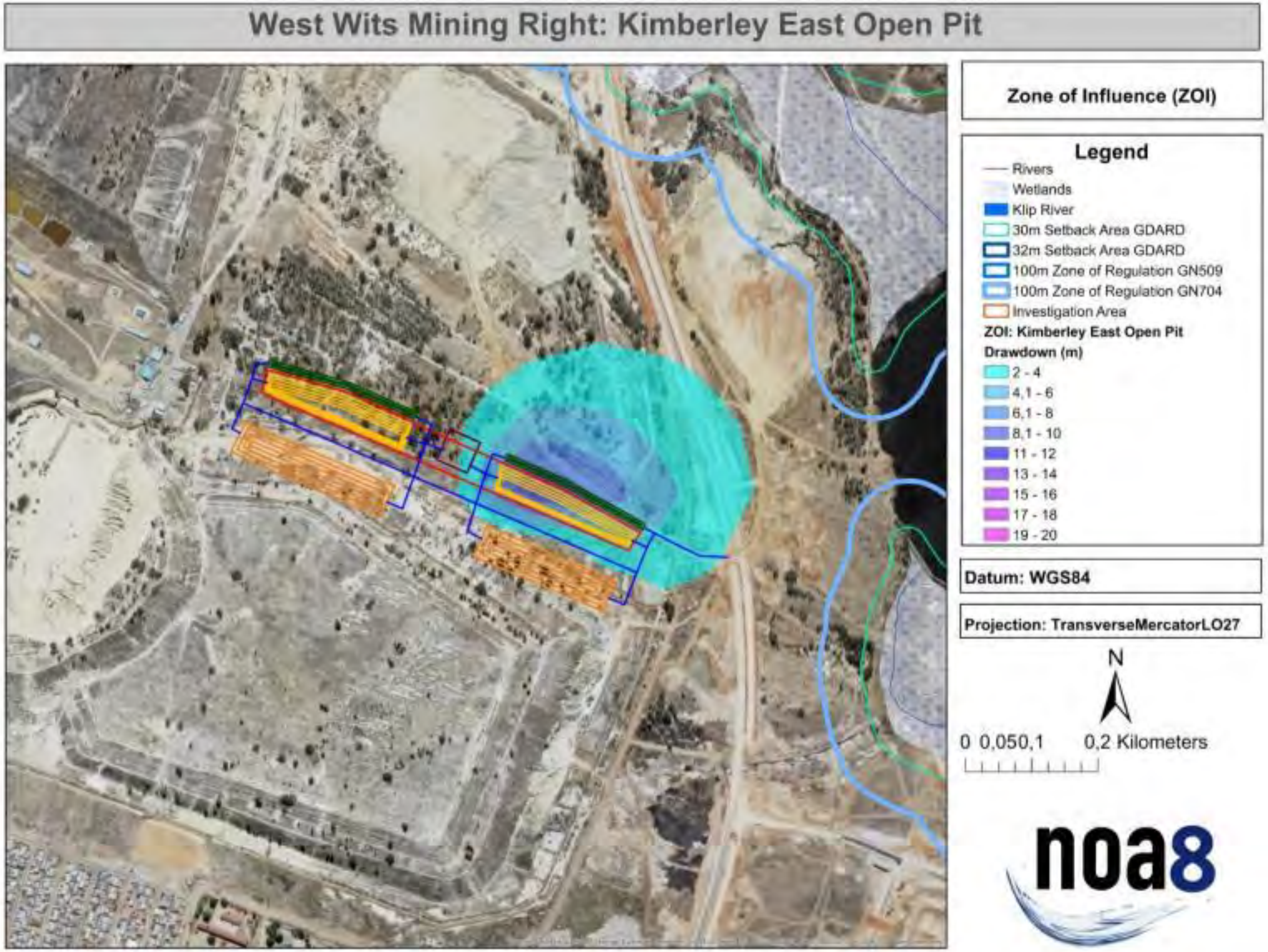


Figure 10-6 Simulated zone of influence (ZOI) associated with the Kimberley Reef East open pit

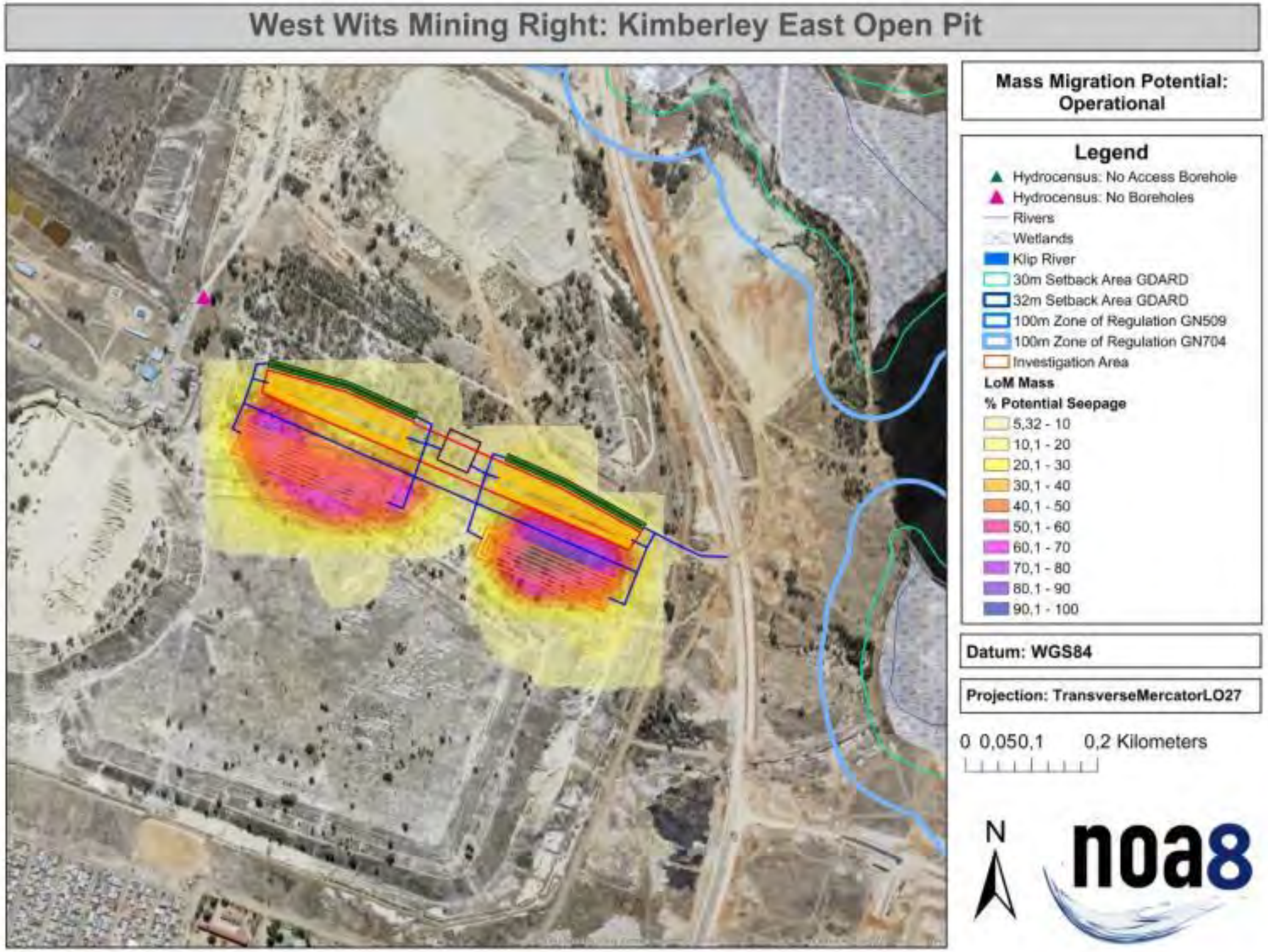


Figure 10-7 Kimberley Reef East WRD potential mass migration during operations

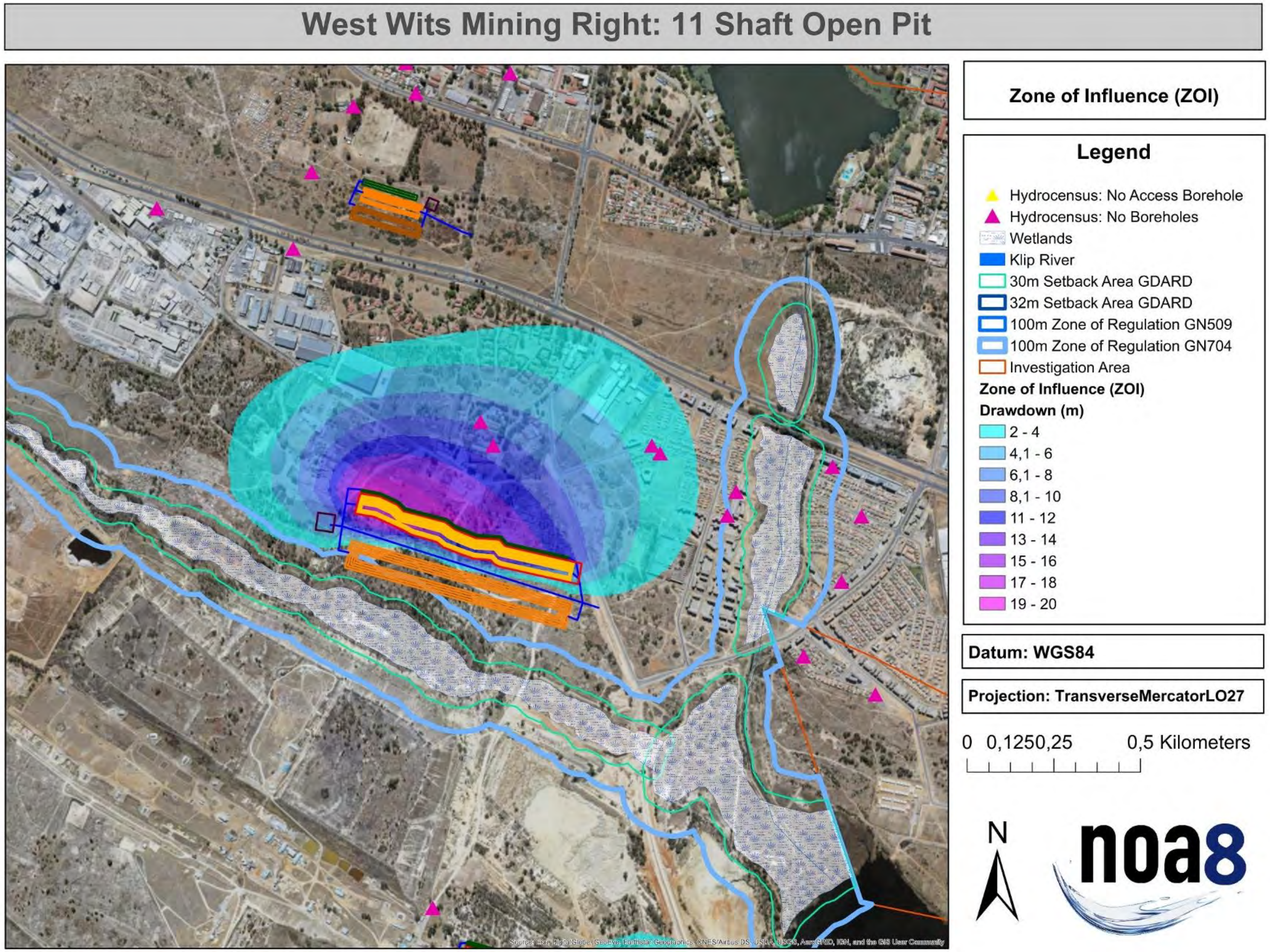


Figure 10-8 Simulated ZOI associated with the 11 Shaft open pit

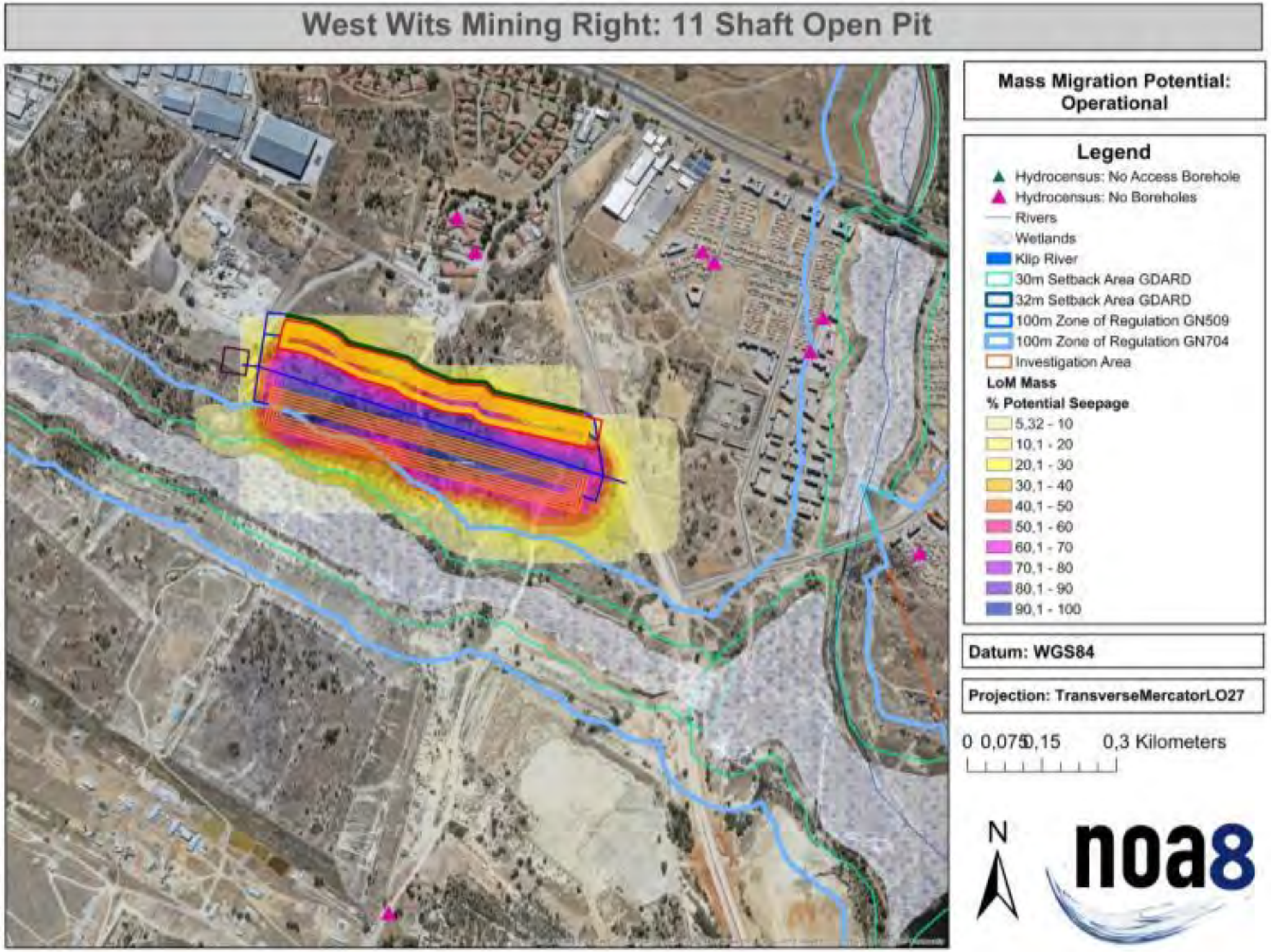


Figure 10-9 11 Shaft WRD potential mass migration during operations

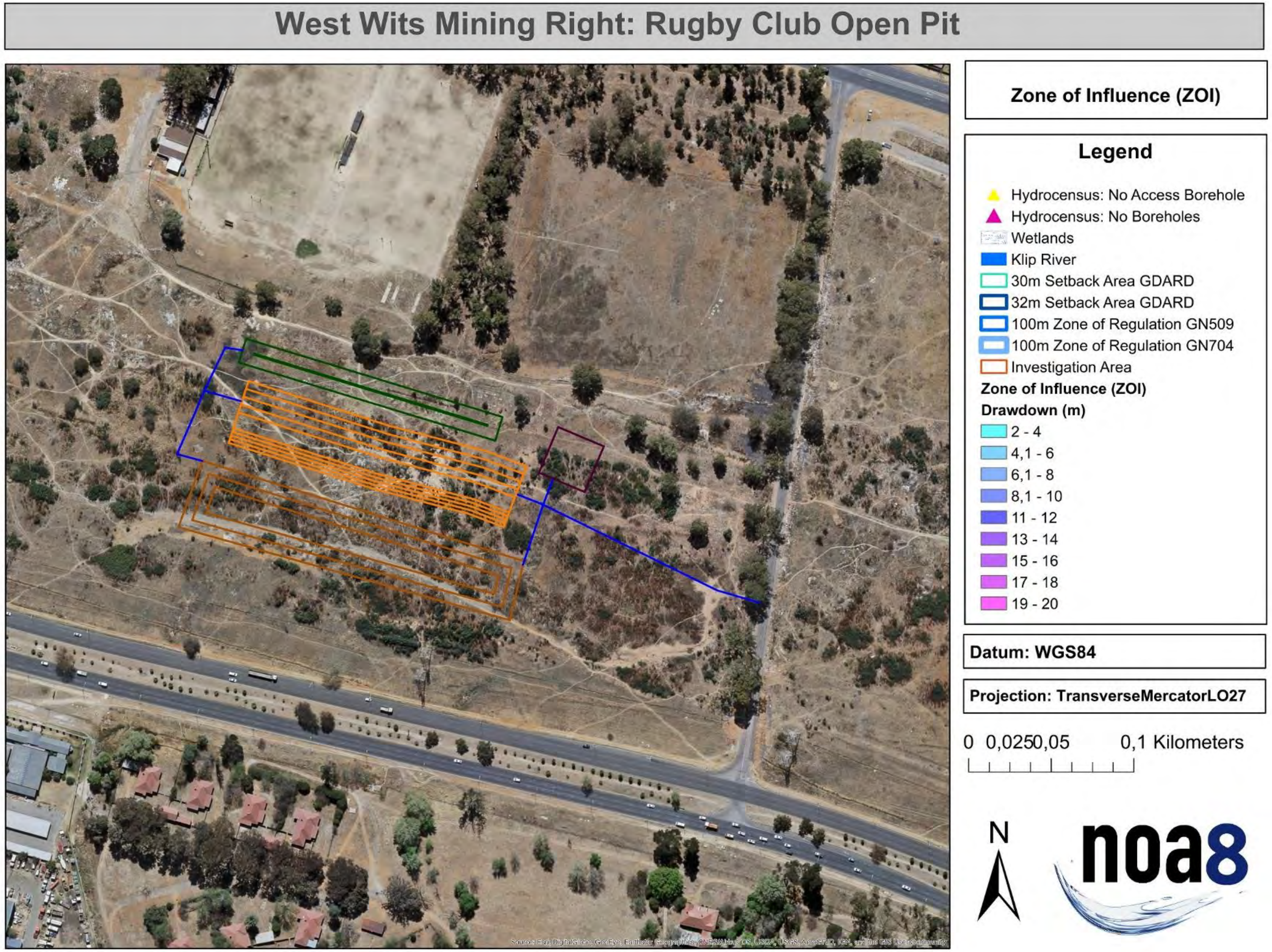


Figure 10-10 Simulated ZOI associated with the Rugby Club open pit

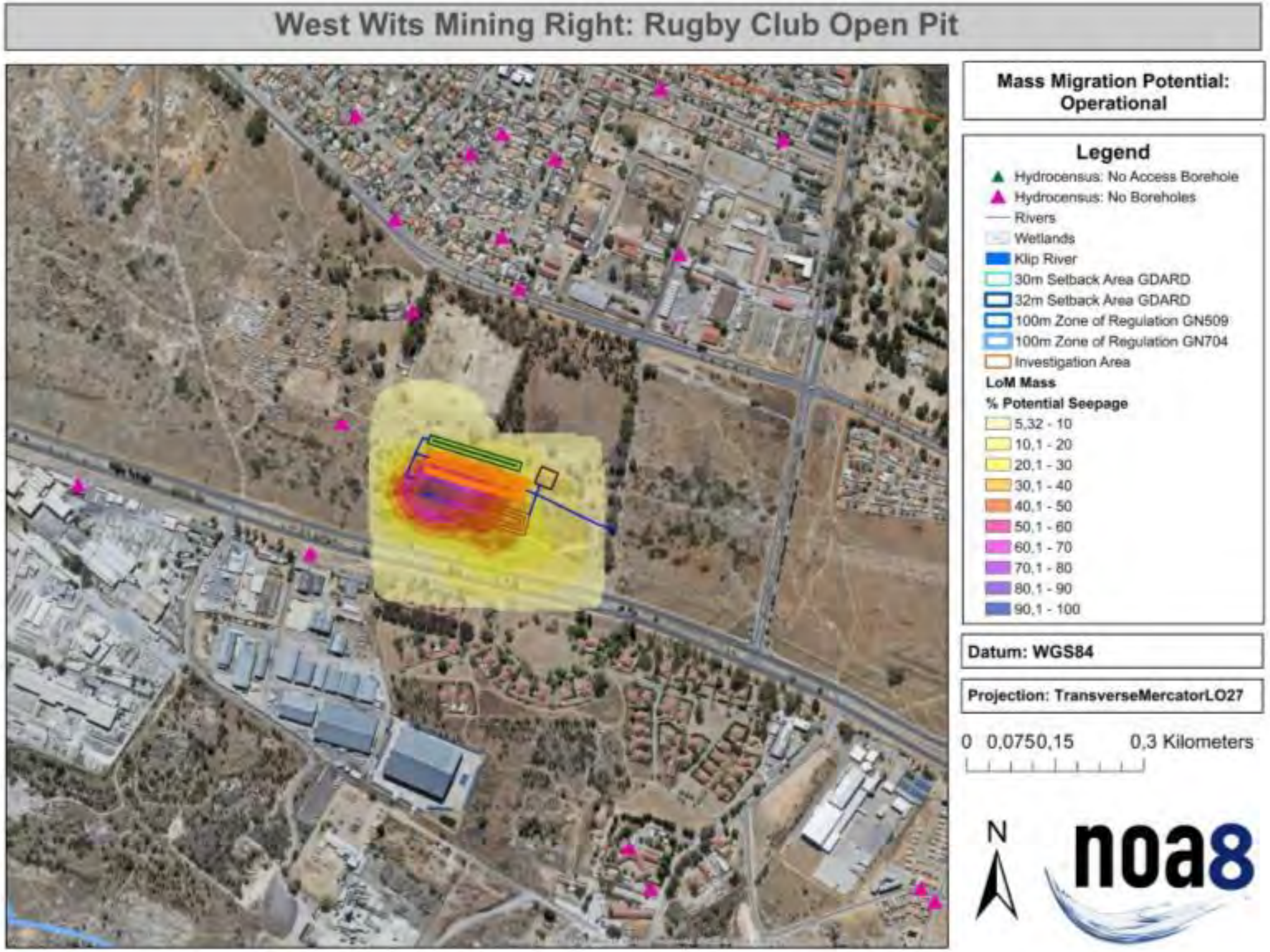


Figure 10-11 Rugby Club WRD potential mass migration during operations

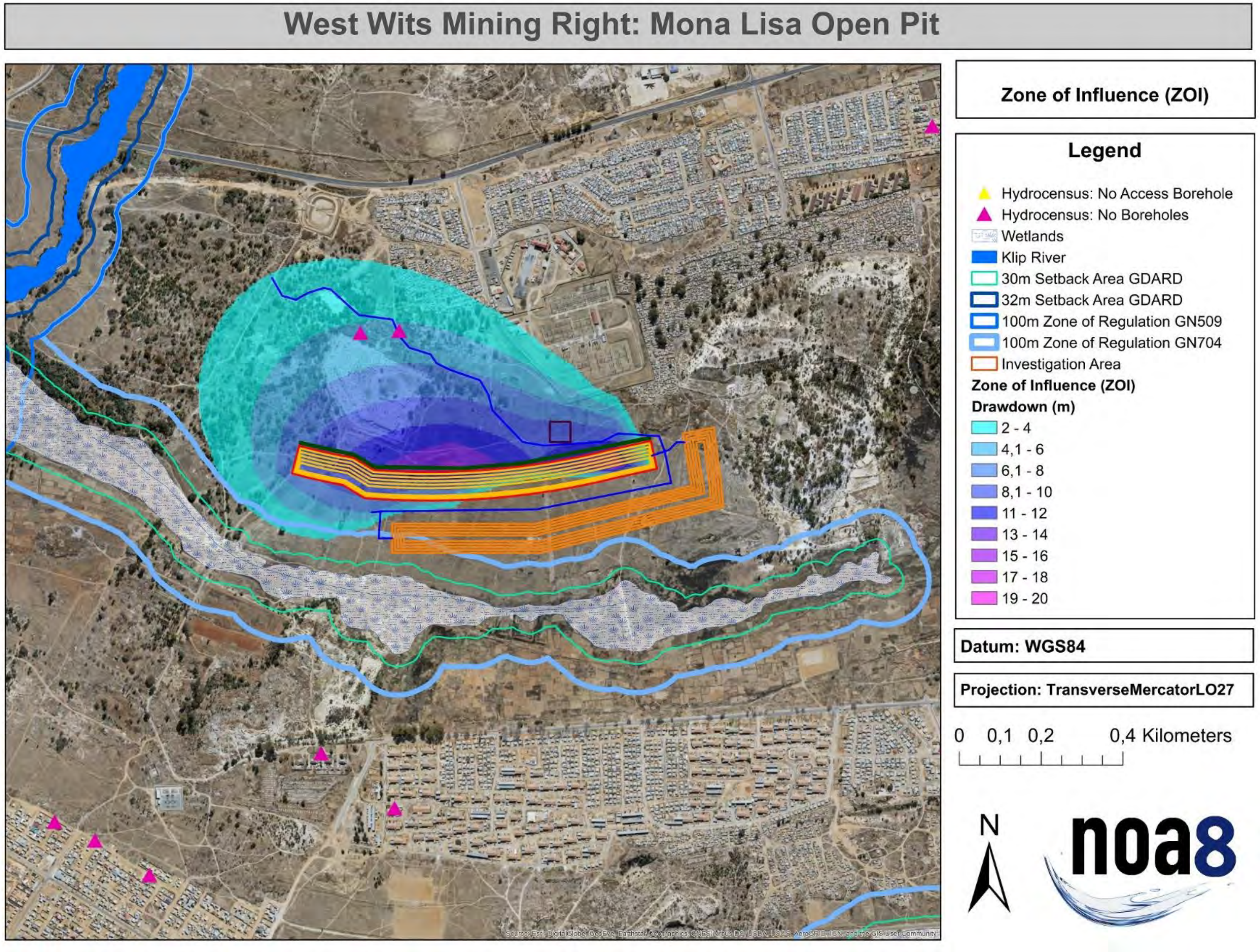


Figure 10-12 Simulated zone of influence (ZOI) associated with the Mona Lisa open pit

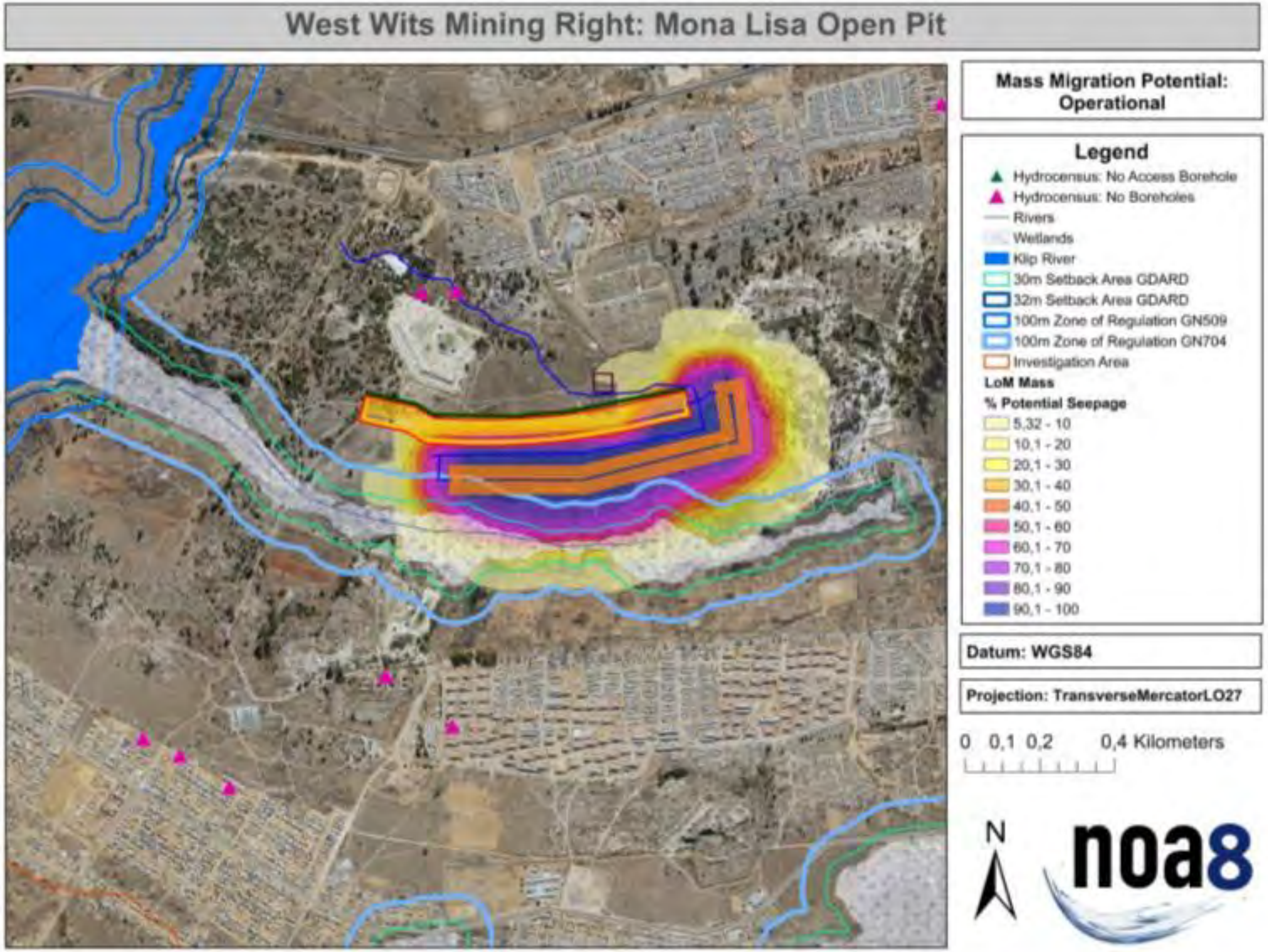


Figure 10-13 Mona Lisa WRD potential mass migration during operations

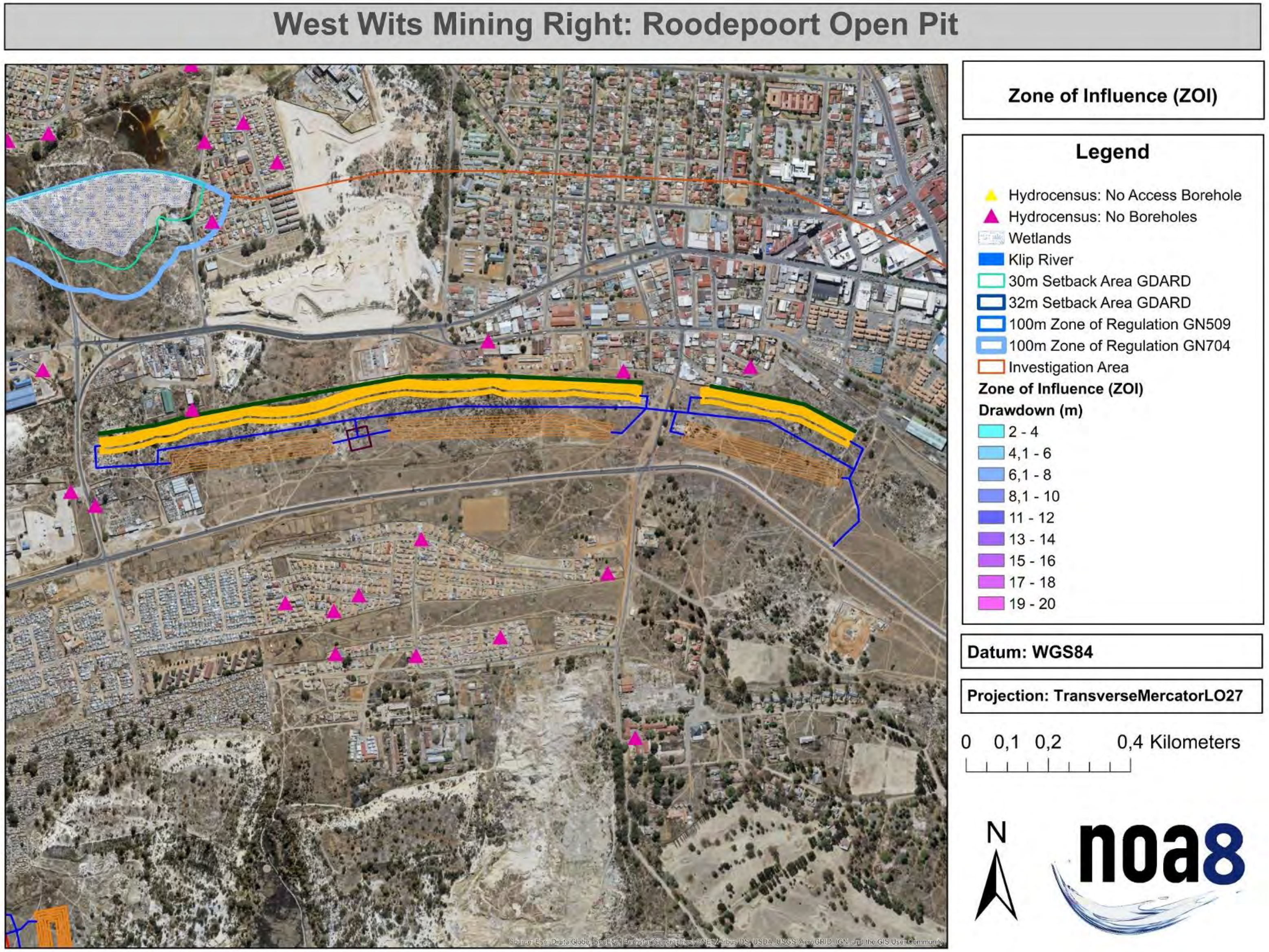


Figure 10-14 Simulated zone of influence (ZOI) associated with the Roodepoort open pit

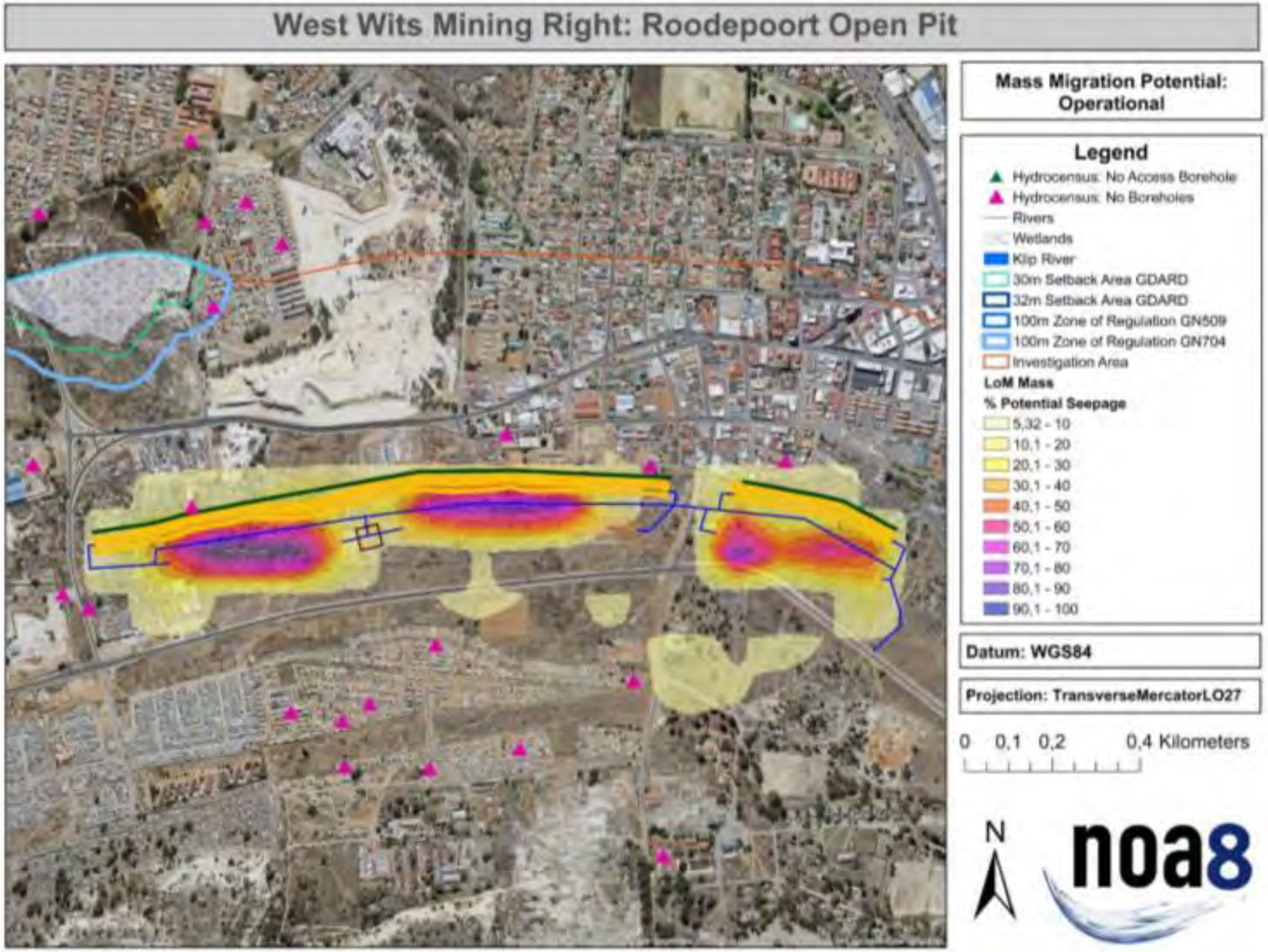


Figure 10-15 Roodepoort WRD potential mass migration during operations

## 10.4 Underground mine dewatering

### 10.4.1 Historical data review and summary

Due to the history of mining in the Witwatersrand basin, it was deemed important to provide background on the proposed underground mining setting:

1. The Central Rand basin can be divided into three sub-basins due to mining pillars and installations of plugs:
    a. Durban Roodepoort Deep Limited (DRD) and Rand Leases Sub Basin
    b. The Central Sub-Basin
    c. The East Rand Proprietary Mines Limited (ERPM) Sub-Basin
2. The proposed underground mining projects is located within the DRD sub-basin/compartment within the Central Rand Basin.
3. The water table in the DRD sub-compartment remains stable, suggesting that a holing (hydraulic connection) towards Rand Leases was reached or seepage occurs towards Doornkop Mine. Doornkop reported historical increases of 5 Ml/day (Golder, 2005).
4. The sub-compartment towards the east i.e. Rand Leases has reached the holing and decants into the Central sub-compartment.
5. In 1977 the deeper mine workings within the Central Rand basin were flooded to a level of 745 m amsl (Scott,1955). ERPM ceased pumping in October 2008 and the mines commenced with flooding and still floods.
6. The natural aquifers were presented by Scott (1995) in a conceptual model indicating the vertical permeability at the base of the perched aquifers to be limiting any vertical flow i.e. between the perched aquifers and the mine voids.
7. This is confirmed by the shallow water levels measured during the hydrocensus compared with historical water levels i.e. between 3 – 17 m below surface.
8. Recharging of the underlying aquifer and mine voids occur at outcrops and faults/fractures that link the perched aquifer with the mine voids. Dewatering and zone of influence is limited in areal extent (<50m radii) and establishes at reef outcrops and shafts. The extent is a function of the local geology and may vary from site to site.
9. The nett influx due to recharge of natural aquifers, ingress through reef outcrops and river direct recharge varies between 17.29 Ml/day in the wet season and 7.35 Ml/day in the dry season for the DRD and Rand Leases Sub Basin.
10. The last water levels recorded at DRD No. 6 shaft was on 10 August 2008 and equated to 1053.80 mamsl.
11. The water in the DRD compartment was believed to rise to an elevation of 1 241.80 m amsl and then decant into the Rand Leases compartment.
12. 1 520 mamsl is the Environmental Critical Limit (ECL) level at which the groundwater is suggested to be maintained and taken as the current water table value in the DRD compartment for simulation purposes.
13. Current mining at Kimberely Reef East is proposed to commence at approximately 1 600 mamsl and reach 1 000 mamsl after 20 years of mining at a surface elevation of approximately 1 725 mamsl.
14. The top of the Bird Reef Circular shaft is 1 742 mamsl. The main drive going to the ore body is 1 587 mamsl and final depth 1 113 mams after 13 years of mining.

### 10.4.2 Infrastructure

Upon reestablishment of the underground operations in Year 4, new infrastructure will be constructed at the Bird Reef Central (Circular Shaft) and Kimberly Reef East complexes. The purpose of these infrastructure sites will be to service the managerial, supervisory and operational requirements of the respective underground targets. A layout of the proposed infrastructure at Bird Reef Central is presented in Figure 10-16. This site will also service the managerial requirements of future underground targets. A layout of the Kimberly Reef East infrastructure site is presented in Figure 10-17.

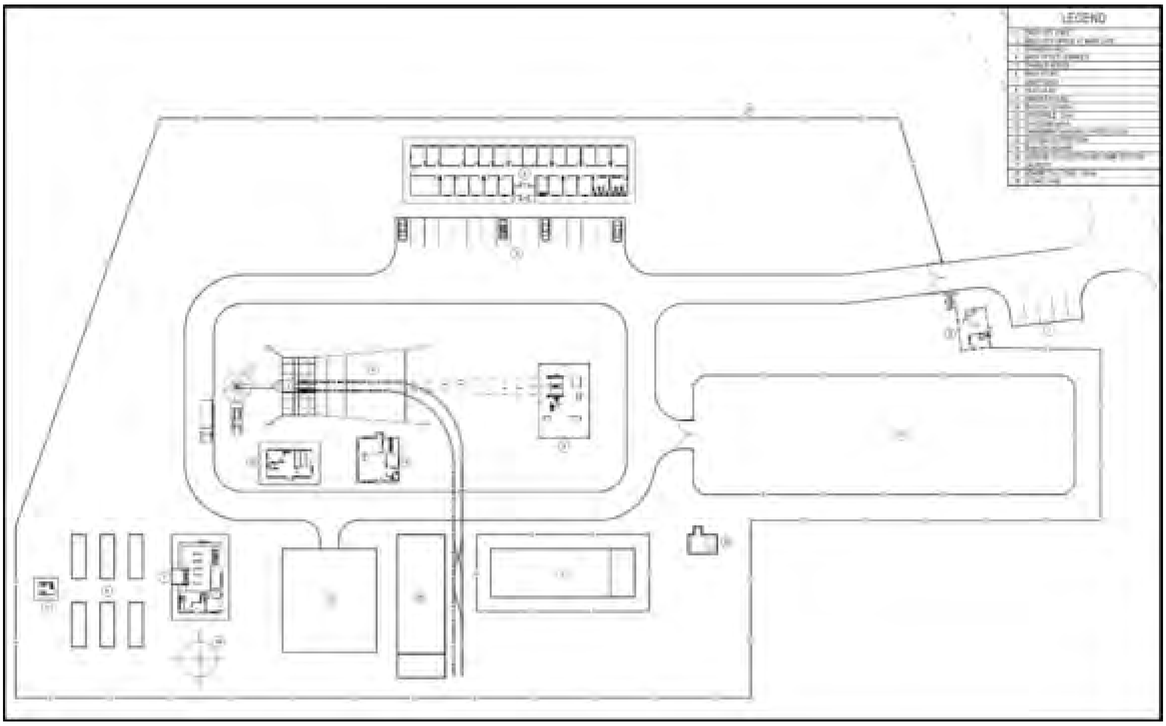


Figure 10-16 Bird Reef Central Infrastructure Complex

The Bird Reef Central office complex will comprise;

- o Security Office at main gate
- o Parking
- o Laydown area and yard store
- o Main office complex
- o Change house and walkway
- o Main Store
- o Lamp Room
- o Headgear
- o Winder House
- o Medical Centre
- o Banksmans Cabin and Proto Room
- o Potable Water Tanks
- o Main Workshop
- o Laundry
- o Perimeter Fencing
- o Internal Access Roads

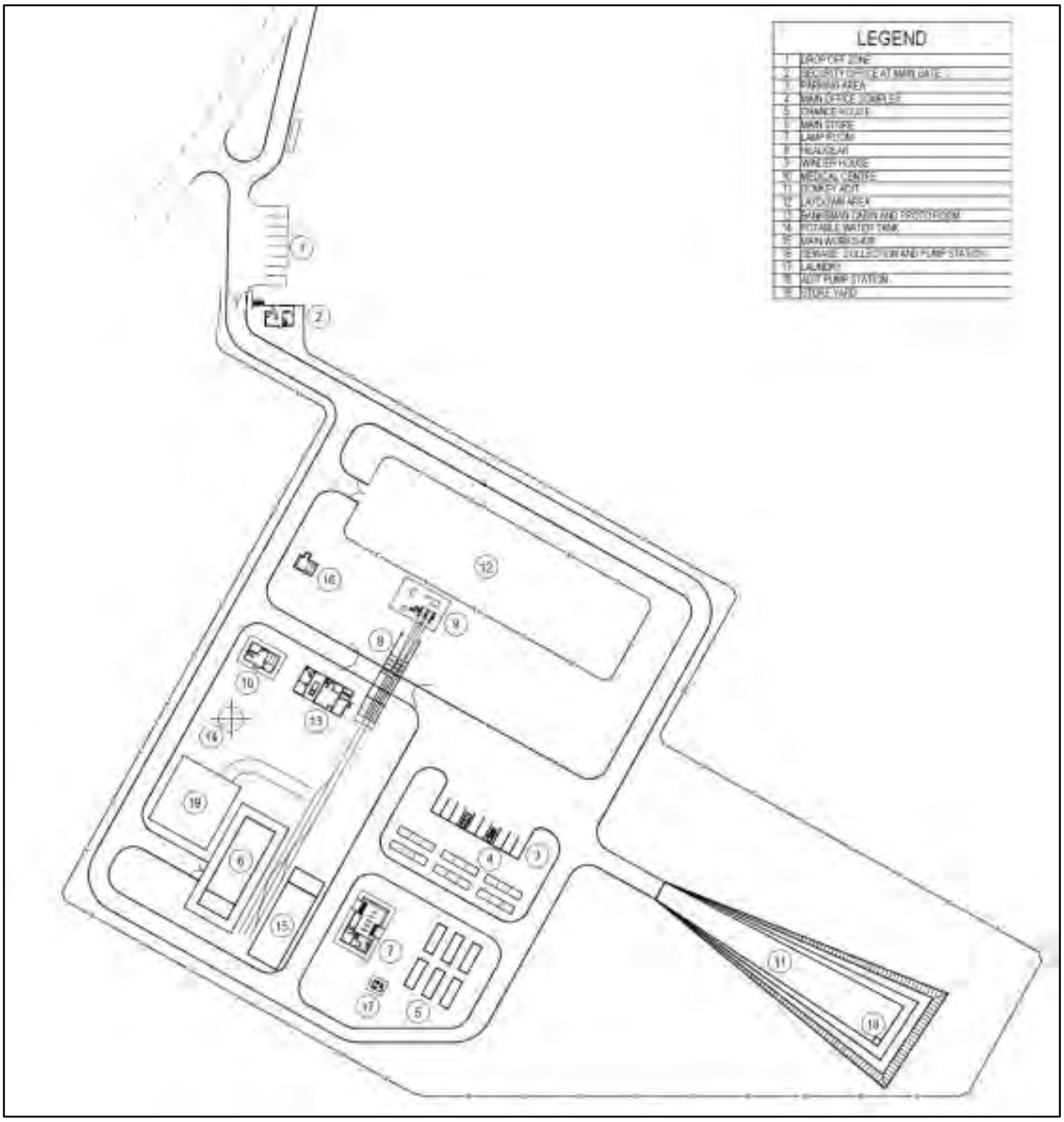


Figure 10-17 Kimberly Reef East Infrastructure Complex

The infrastructure at the Kimberly Reef East site is planned to include;

- Parking
- Security office at main gate
- Change house and walkway
- Lamp room
- Medical centre
- Headgear
- Winder house
- Laydown area and yard store
- Stores
- Workshop
- Offices

- o Potable water tanks
- o Banksmans cabins
- o Explosives handling facilities
- o Internal Roads
- o Store Yards
- o Haul Roads
- o Perimeter Fencing

Electricity and water will be provided to these areas from the municipal facilities. Access to the sites will be from the existing local road networks.

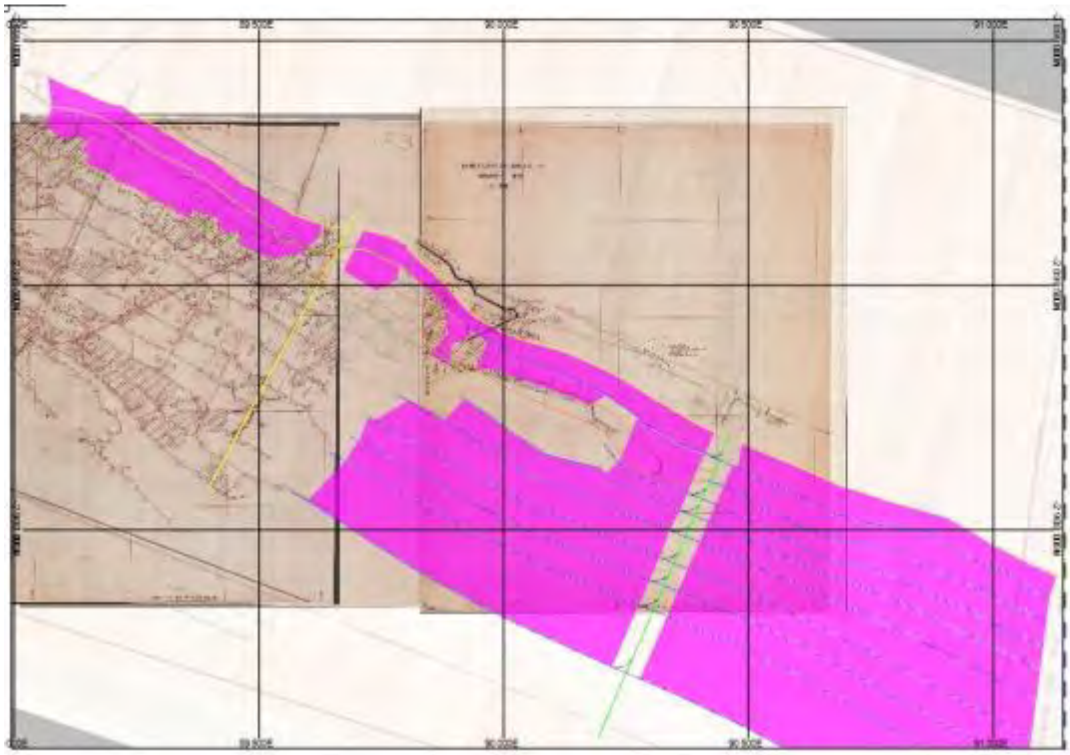

Figure 10-18 Kimberly Reef East Underground Mine Workings Layout

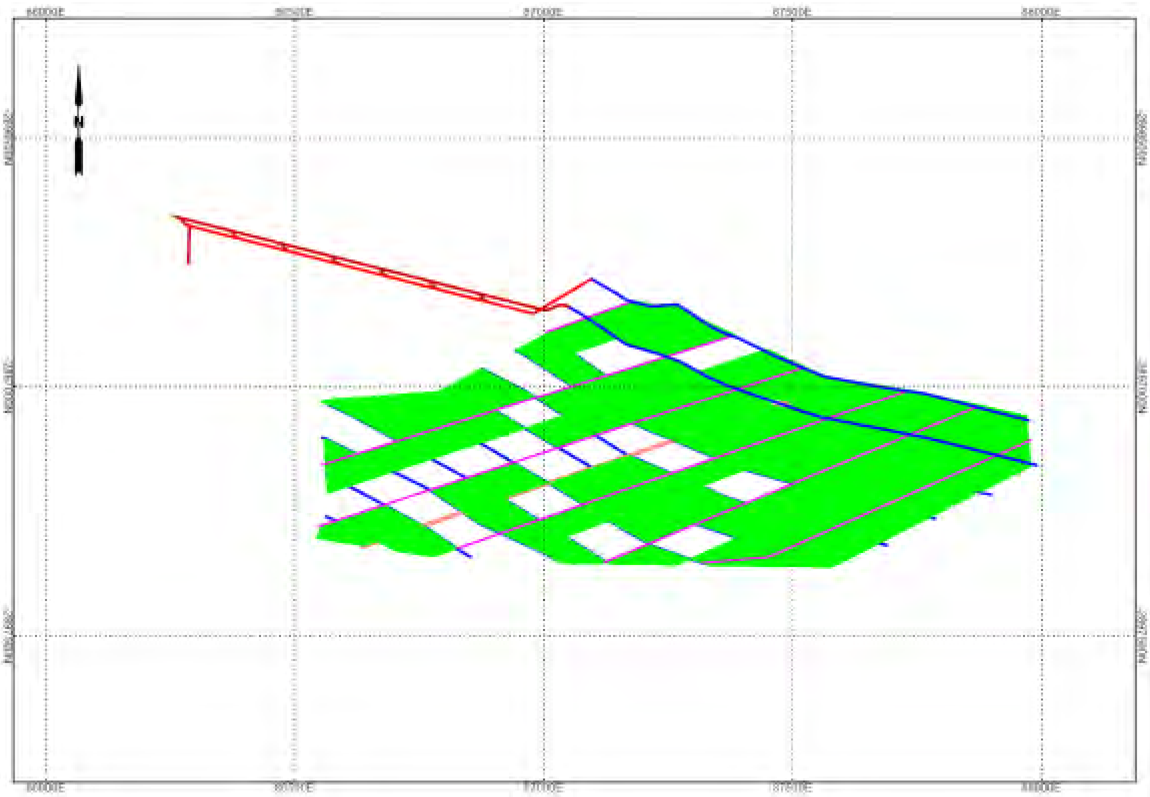

Figure 10-19 Bird Reef Central Underground Mine Workings Layout

### 10.4.3 Simulated impacts

The assessment of the potential underground mining impacts was simulated by including the proposed underground mines in the 3D numerical model. It should be noted that no site-specific hydraulic parameters were available for the underground mining reefs and it is proposed that this should be verified by means of drilling (core drilling for resource estimations) and packer testing conducted at depth at various intervals.

The proposed packer test will provide valuable information on the hydraulic setting of the proposed underground mines and this will directly influence the dewatering volumes simulated and expected. More than this, the proposed underground mines are located in a basin impacted by historical mining, both documented and undocumented. It is the undocumented influences of mining that needs to be assessed:

1. Current groundwater levels.
2. Recharge components other than precipitation i.e. flow and leakage from neighbouring flooded compartments. A water pillar is part of the underground design and should limit inflow into the underground mine workings, however, discrete fractures requires assessment with drilling and packer tests.
3. Direct linkage and overflow into and from various compartments. Dewatering volumes will be substantially more than simulated should a link exist between the proposed mine area and a flooded neighbouring compartment. This is potentially the biggest required assessment for the follow up phase.

The simulated qualified dewatering volumes are provided in Figure 10-20. The volumes provided should be used for planning purposes until additional investigations are conducted to assess the hydraulic characteristics associated with the underground mines. The dewatering volumes range between 500 and just over 2 000 $m^3/d$ at the end of the simulated mining for Bird Reef Central and 800 and 3 600 $m^3/d$ for Kimberley Reef East underground mine. The envelope of uncertainty requires attention to increase the confidence level of the possible dewatering rates.

The simulated zone of influence should not be measured, or recorded, on or close to surface. Shallow groundwater levels remain even with the historical mining in the basins, mostly due to the low vertical hydraulic permeability of the shallower formations.

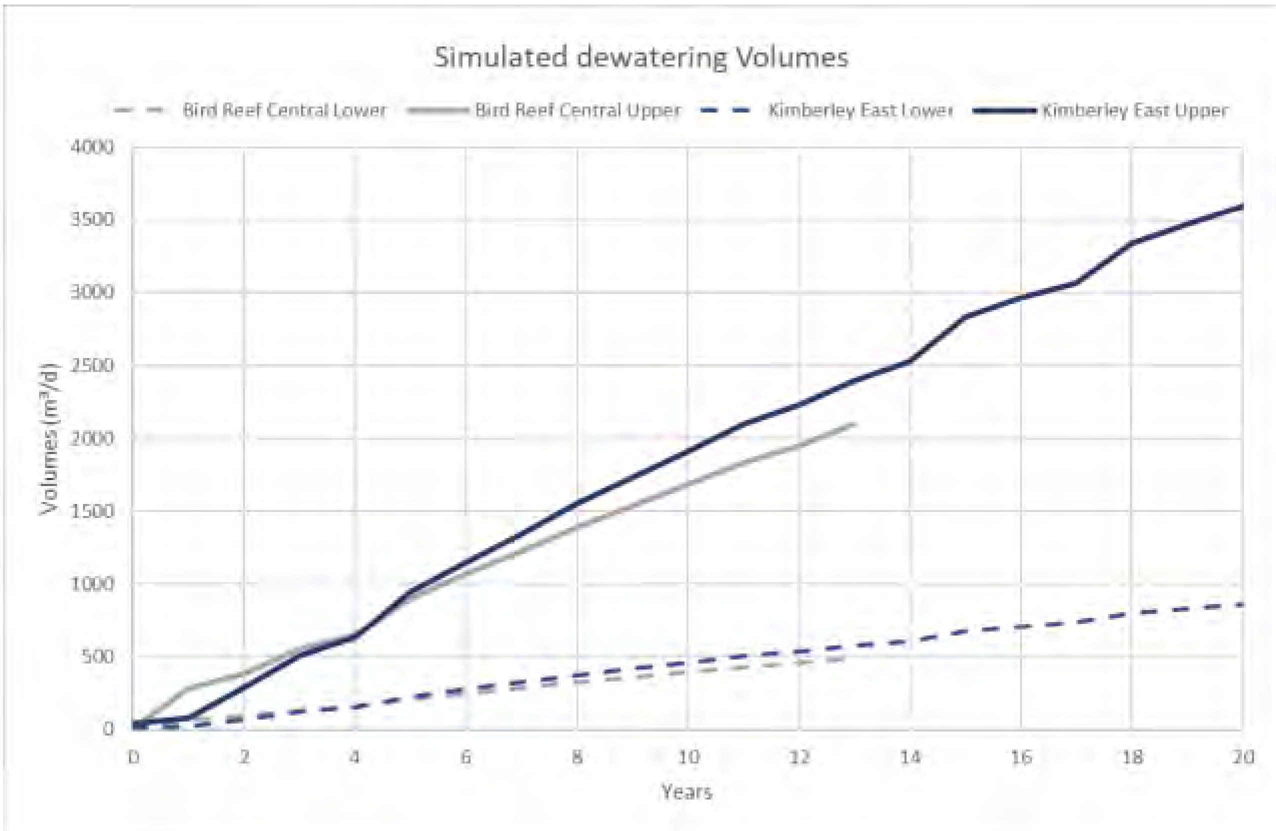


Figure 10-20 Simulated dewatering volumes for the Kimberley Reef East and Bird Reef Central underground mine workings (upper and lower simulated limits)

# 11 Environmental Impact Matrix

## 11.1 Methodology used in determining the significance of environmental impacts

The method used for the assessment of environmental issues is set out in Table11-1. This assessment methodology enables the assessment of environmental issues including: cumulative impacts, the severity of impacts (including the nature of impacts and the degree to which impacts may cause irreplaceable loss of resources), the extent of the impacts, the duration and reversibility of impacts, the probability of the impact occurring, and the degree to which the impacts can be mitigated.

Table11-1 Impact assessment methodology

*Note: Part A provides the definition for determining impact consequence (combining intensity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.*

| **PART A: DEFINITION AND CRITERIA*** | | |
|---|---|---|
| **Definition of SIGNIFICANCE** | | **Significance = consequence x probability** |
| **Definition of CONSEQUENCE** | | **Consequence is a function of severity, spatial extent and duration** |
| **Criteria for ranking of the SEVERITY of environmental impacts** | **H** | Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. |
| | **M** | Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. |
| | **L** | Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. |
| | **L+** | Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. |
| | **M+** | Moderate improvement. Will be within or better than the recommended level. No observed reaction. |
| | **H+** | Substantial improvement. Will be within or better than the recommended level. Favourable publicity. |
| **Criteria for ranking the DURATION of impacts** | **L** | Quickly reversible. Less than the project life. Short term |
| | **M** | Reversible over time. Life of the project. Medium term |
| | **H** | Permanent. Beyond closure. Long term. |
| **Criteria for ranking the SPATIAL SCALE of impacts** | **L** | Localised - Within the site boundary. |
| | **M** | Fairly widespread – Beyond the site boundary. Local |
| | **H** | Widespread – Far beyond site boundary. Regional/ national |

**PART B: DETERMINING CONSEQUENCE**

**SEVERITY = L**

| | | | | | |
|---|---|---|---|---|---|
| **DURATION** | Long term | **H** | **Medium** | **Medium** | **Medium** |
| | Medium term | **M** | **Low** | **Low** | **Medium** |
| | Short term | **L** | **Low** | **Low** | **Medium** |

**SEVERITY = M**

| | | | | | |
|---|---|---|---|---|---|
| **DURATION** | Long term | **H** | **Medium** | **High** | **High** |
| | Medium term | **M** | **Medium** | **Medium** | **High** |
| | Short term | **L** | **Low** | **Medium** | **Medium** |

**SEVERITY = H**

| | | | | | |
|---|---|---|---|---|---|
| **DURATION** | Long term | **H** | **High** | **High** | **High** |
| | Medium term | **M** | **Medium** | **Medium** | **High** |
| | Short term | **L** | **Medium** | **Medium** | **High** |
| | | | **L** | **M** | **H** |
| | | | Localised<br>Within site boundary<br>Site | Fairly widespread<br>Beyond site boundary<br>Local | Widespread<br>Far beyond site boundary<br>Regional/ national |
| | | | **SPATIAL SCALE** | | |

| **PART C: DETERMINING SIGNIFICANCE** | | | | | |
|---|---|---|---|---|---|
| **PROBABILITY (of exposure to impacts)** | Definite/ Continuous | **H** | **Medium** | **Medium** | **High** |
| | Possible/ frequent | **M** | **Medium** | **Medium** | **High** |
| | Unlikely/ seldom | **L** | **Low** | **Low** | **Medium** |
| | | | **L** | **M** | **H** |
| | | | **CONSEQUENCE** | | |

| **PART D: INTERPRETATION OF SIGNIFICANCE** | |
|---|---|
| **Significance** | **Decision guideline** |
| High | It would influence the decision regardless of any possible mitigation. |
| Medium | It should have an influence on the decision unless it is mitigated. |
| Low | It will not have an influence on the decision. |

***H = high, M= medium and L= low and + denotes a positive impact.**

## 11.2 Identified environmental impacts

### 11.2.1 Mine dewatering and influence on groundwater levels

This impact is associated with the lowering of groundwater levels due to intersecting of groundwater table during the mining process. The assessment was done for all the open pits and underground mines.

<u>Impact Identified</u>: Zero to little influence on the local groundwater regime was simulated due to the shallow pit and deep groundwater levels:

1. Mona Lisa Open Pit: Lowering of groundwater levels were simulated in a limited extent
2. Roodepoort Open Pit: No impact on groundwater levels simulated
3. Rugby Club Open Pit: No impact on groundwater levels simulated
4. 11 Shaft Open Pit: Lowering of groundwater levels were simulated in a limited extent
5. Kimberley East Reef Open Pit: Lowering of groundwater levels were simulated in a limited extent
6. Underground Mining: Little to no impact on the groundwater levels due to underground mining.

The local groundwater level should be confirmed prior to the commencement of mining at each open pit i.e. shallow drill hole to proposed mining depth. No 3$^{rd}$ party groundwater users were detected within the simulated zone of influences due to the open pit mining. The underground mining poses little to no impact on the surface and shallow groundwater regime and users. The underground mine's decanting is controlled due to the connections between the various basins, of which the 1520 mamsl is the Environmental Critical Limit (ECL) level at which the groundwater is suggested to be maintained. Decanting is not a possibility in the proposed mined basin.

The associated simulated impacts are medium to low and should there be a limited impact, it can be fully reversed.

Proposed mitigation: No mitigation is required. Seasonal dewatering might be required due to storm events and surface water runoff. The water captured is classified as contact water and should be kept in a closed circuit.

The groundwater model and associated recommendations should be reviewed and updated if any groundwater users are identified during the updated focused hydro census at each open pit before mining commences.

The decanting of water accumulating in the open pits is not foreseen, however, the monitoring protocol should monitor the groundwater levels (and quality) within the rehabilitated open pit for at least 2 years post mining.

### 11.2.2 Mass migration from the WRD

This impact is associated with possible mass migration from the temporarily WRD's associated with each open pit. The material will be used to concurrently backfill the open pit. No blasting will take place; hence no nitrates are introduced to the system. The geochemical assessment also indicted no potential leachates from the WRD material. Hence from the onset, the potential impact is low.

Impact Identified: The potential of the WRDs to leach minerals into the receiving environment and negatively influencing the groundwater and surface water quality. The simulations were done for each open pit WRD:

1. Mona Lisa Open Pit: Minimum impact simulated on tributary located to the south of the WRD
2. Roodepoort Open Pit: No impact simulated on any recorded sensitive receptor
3. Rugby Club Open Pit: No impact simulated on any recorded sensitive receptor
4. 11 Shaft Open Pit: Minimum impact simulated on tributary located to the south of the WRD
5. Kimberley East Reef Open Pit: No impact simulated on any recorded sensitive receptor.

Proposed mitigation: During operations the potential mass migration from the WRDs will migrate a maximum distance of 150 m. This is only potential seepage since little to no leachate is expected (GeoDyn, 2018).

The potential seepage exiting the proposed infrastructure remains less than 20% and interacts with groundwater.

Monitoring boreholes should be implemented as follows:

1. In the backfilled open pit areas post closure
2. Mona Lisa Open Pit: Between the WRD and the tributary to the south and between the open pit and the Klip River to the west.
3. Roodepoort Open Pit: South of the western WRD
4. Rugby Club Open Pit: North of the open pit between the open pit and the school fields
5. 11 Shaft Open Pit: North of the open pit and between the WRD and the tributary to

the south

6. Kimberley East Reef Open Pit: North of the eastern open pit.

### 11.2.3 Mass migration from the backfilled open pit

Impact Identified: The potential of the backfilled open pits to leach minerals into the receiving environment and negatively influencing the groundwater and surface water quality.

Impact significance

Proposed mitigation: The open pits will be concurrently backfilled with the waste from the WRD during operations and finalised post operation. The area should be rehabilitated to achieve a post-closure land use as agreed with the respective landowners. This should be done in a manner that decreases recharge from precipitation. Ongoing monitoring as proposed should be conducted at least 2 years post operations.

The results of the assessment are shown in Table 11-2. The results indicate that the significance of potential impacts rate as *Very Low*. The cumulative impacts of the impacts rate as *Low*. This is predominantly because the development of AMD conditions as well as the leaching of contaminants from the waste rock is unlikely and that no groundwater users have been recorded in the potential zone of influence due to mining. The dewatering zone of influence indicates little to no impact on recorded users (to be updated with the hydrocensus before mining commences) and rate *Very Low.*

Detailed simulation results are provided in Figure 10-6 to Figure 10-15.

Table 11-2 Environmental impact assessment matrix for geohydrological impacts

| Potential Impact | Activity | Alternative | Project Phases | Without Mitigation | | | | | | | | With Mitigation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | | | | Degree to which impact can: | | | Consequence | | | | | Degree to which impact can: | | |
| | | | | Severity | Duration | Spatial Scale | Probability | Significance | be reversed | cause irreplaceable loss of resource | be avoided/ Managed/ Mitigated | Severity | Duration | Spatial Scale | Probability | Significance | be reversed | cause irreplaceable loss of resource | be avoided/ Managed/ Mitigated |
| Lowering of groundwater level at Mona Lisa Open Pit | Mining at the open pit, intersecting groundwater table | All | O | M | L | L | M | M | Fully | Unlikely | Managed / Mitigated | M | L | L | M | L | Fully | Unlikely | Managed / Mitigated |
| Impact of water quality of the Klip River due to mining at Mona Lisa Open Pit | Open pit mining<br>Disposal of waste | All | C,O,D,Cl | M | L | L | M | M | Fully | Unlikely | Managed / Mitigated | L | L | L | L | L | Fully | Unlikely | Managed / Mitigated |
| Impact of water quantity of the Klip River due to mining at Mona Lisa Open Pit | Open pit mining<br>Disposal of waste | All | C,O,D | M | L | L | M | M | Fully | Unlikely | Managed / Mitigated | L | L | L | L | L | Fully | Unlikely | Managed / Mitigated |
| Mass migration from WRDs negatively impacting groundwater quality: Mona Lisa Open Pit | Disposal of waste | All | O,D | M | L | L | M | M | Fully | Unlikely | Managed / Mitigated | L | L | L | L | L | Fully | Unlikely | Managed / Mitigated |
| Lowering of groundwater level at Roodepoort Open Pit | Mining at the open pit, intersecting groundwater table | All | O | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Mass migration from WRDs negatively impacting groundwater quality: Roodepoort Open Pit | Disposal of waste | All | O,D | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Lowering of groundwater level at 11 Shaft Open Pit | Mining at the open pit, intersecting groundwater table | All | O | M | L | L | M | M | Fully | Unlikely | Managed / Mitigated | L | L | L | L | L | Fully | Unlikely | Managed / Mitigated |
| Mass migration from WRDs negatively impacting groundwater quality: 11 Shaft Open Pit | Disposal of waste | All | O,D | M | L | L | M | M | Fully | Unlikely | Managed / Mitigated | L | L | L | L | L | Fully | Unlikely | Managed / Mitigated |
| Lowering of groundwater level at Rugby Club Open Pit | Mining at the open pit, intersecting groundwater table | All | O | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Mass migration from WRDs negatively impacting groundwater quality: Rugby Club Open Pit | Disposal of waste | All | O,D | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Lowering of groundwater level at Kimberley Reef East Open Pit | Mining at the open pit, intersecting groundwater table | All | O | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Mass migration from WRDs negatively impacting groundwater quality: Kimberley Reef East Open Pit | Disposal of waste | All | O,D | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Lowering of groundwater level due to underground mining at Circular Shaft and Kimberley East Underground Mine | Mining at depth, intersecting groundwater table and lowering of the regional water table | All | O | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |
| Mass migration from rehabilitated open pits negatively impacting groundwater quality | Rehabilitating open pits with waste from WRD | All | O,D | L | L | L | L | M | Fully | Unlikely | be avoided/ Managed/ Mitigated | L | L | L | L | L | Fully | Unlikely | be avoided/ Managed/ Mitigated |

# 12 Conclusions

1. Groundwater and Aquifer Characterisation:
    a. Groundwater vulnerability indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system at some location above the uppermost aquifer. The Witwatersrand and Ventersdorp Formations (local aquifers) are least vulnerable.
    b. Based on the aquifer classification map published by the DWS in August 2012 the aquifer classification system defines the Witwatersrand and Ventersdorp Formations as minor aquifers.
    c. Aquifer susceptibility is a qualitative measure of the relative ease with which a groundwater body can potentially be contaminated by anthropogenic activities and includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification. Based on the classification above the Witwatersrand and Ventersdorp Formations have a low susceptibility to contamination.
2. A project wide hydrocensus was completed in 2018 and 13 boreholes were identified, of which only four water levels could be measured. An additional 123 properties were assessed, however, the land owners indicated that no boreholes are located on these properties.
3. Data for the dolomitic monitoring boreholes were assessed. These data points are located more than 10 km south of the proposed West Wits project area.
4. Samples were taken at six boreholes and four surface water points. The majority of the samples indicated historical and present influences rendering the water unfit for human consumption. This indicated a high present impact on the baseline groundwater and surface water environments. Based on the SANS241 drinking water guideline the sampled groundwater and surface water is not fit for human consumption (unless treated).
5. The groundwater flow model should be viewed as/at a conceptual level and qualified rather than calibrated due to the limited number of groundwater sites available to populate the numerical groundwater flow model, and the absence of local groundwater sites at the proposed open pits.
6. The groundwater numerical model was used to simulate the potential impact of the open pit mines on the local groundwater regime and the WRDs on the local groundwater quality.
7. Little to no mine dewatering is foreseen due to the shallow open pits proposed (i.e. $<30$ m deep). Minor seepage and dewatering could be required during the wet season and runoff from the WRD and local catchment. The Mona Lisa pit could yield higher dewatering volumes due to the proximity to the Klipriver.
8. The geochemical analyses results indicated the waste associated with the open pits is benign. However, for management purposes, mass migration simulations for operational and post operational was simulated to assess possible migration pathways originating from the WRD. Simulated mass migration is low during operations.
9. The simulated underground mining operations requires dewatering volumes of between 500 and 800 $m^3/d$ as lower limits and 2 200 and 3 600 $m^3/d$ as upper limits for Bird Reef Central and Kimberley Reef East respectively. The volumes should be seen as a guide for management purposes, however, additional work is required to assess the local groundwater regime at depth associated with the proposed underground mine workings.

# 13 Recommendations

1. An updated hydrocensus should be completed in a 500 m radius around each open pit and underground mining complex. The data recorded should be used to finalise the monitoring protocol and the groundwater flow model and associated management scenarios. Additional monitoring boreholes should be drilled at each open pit and WRD location should no existing boreholes be found suitable.
2. A detailed monitoring program should be initiated before mining commences (Table 13-1, Figure **14-1**):
   a. Monitoring boreholes should be drilled at each open pit mining area to the south of the WRD positions. At the Mona Lisa pit, a monitoring borehole should be drilled between the open pit and the Kliprivier. Once drilling is completed, an aquifer test should be performed and the water sampled should be compared to the Klipspruit River water to establish a link, or absence there-of, between the potential dewatering at Mona Lisa and the Klipspruit River.
   b. All boreholes should be subjected to aquifer tests to assess aquifer properties to be used in the model update. All boreholes should be sampled and analysed for the full spectrum of metalloids, Uranium and Thorium as well as micro and macro chemical parameters. The results should be recorded as the baseline against which all future possible impacts are measured and managed.
   c. Monitoring (water levels and quality) during mining should be performed monthly due to the short Life of Mine (<12 months). Post operational monitoring should be conducted quarterly for at least two years.
   d. A monitoring borehole should be drilled into the rehabilitated open pit and included in the post operational monitoring protocol. Water levels and water quality should be monitored on a quarterly basis.
   e. Monitoring should continue for at least two years post rehabilitation of the various open pit project areas, conducted quarterly.

**Table 13-1 Indicative moniotring positions**

| BH_ID | Lat | Long |
|---|---|---|
| ML01 | -26.17876 | 27.84173 |
| ML02 | -26.17613 | 27.83789 |
| RD01 | -26.16635 | 27.85204 |
| RC01 | -26.18060 | 27.89480 |
| ES01 | -26.19119 | 27.89435 |
| ES02 | -26.18995 | 27.89923 |
| KR01 | -26.20180 | 27.90234 |
| BRC01 | -26.17781 | 27.87338 |

3. Any water reporting to the open pit or storm water management areas should be kept in a closed system (classified as contact water) and not be discharged into the environment before treatment to the specific catchment Target Water Quality Guideline (TWQG) standards. Contact water can be recirculated and used in a closed system according to GN704 Best Practise Guideline.
4. The back filled open pits should be covered with pre-stripped top soil and revegetated to decrease potential recharge from precipitation.
5. The underground mining should be assessed by drilling boreholes to proposed depth

of mining, intersecting known geological units, fractures and mining sequence. The boreholes should be subjected to packer tests to obtain hydraulic aquifer parameters to be used in updating the groundwater flow model and dewatering simulations.

6. The groundwater flow model should be updated once the hydrocensus and monitoring and testing data is updated, and monitoring points installed.

## 14 Monitoring Program

A monitoring protocol should be adhered to ascertain the sustainability of the water supply and monitor, if any, impacts on neighbouring groundwater users.

Water samples should be analysed at an accredited SANAS laboratory according to the ISO/IEC 17025:2005 standards for the parameters specified.

### 14.1 Water Sampling

Sampling should include the following:

- Purging of boreholes using an open-end bailer system to collect groundwater samples from selected boreholes:
- Groundwater sampling should be conducted in accordance with the minimum requirements for water quality monitoring as specified in the Groundwater Sampling Comprehensive Guide (WRC, 2007);
- Purging is usually done to remove stagnant water from the boreholes; and
- Water quality parameters will be recorded using handheld instruments and recorded on a field sheet.
- Field measurements of pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and temperature in all selected sampling points using handheld meters:
- All handheld apparatus should be calibrated prior to sampling;
- On-site quality measurements should be used to determine the purging time as samples must be collected once field measurements have stabilised (if purging is required);
- The field parameters measured should be presented in a table including at least the following:
    - Borehole Number;
    - Coordinates (Latitude and Longitude);
    - pH;
    - EC (mS/m);
    - TDS (mg/L);
    - Temperature (°C); and
    - Comments / Status.

The collected water samples should be submitted to a South African National Accreditation Systems (SANAS) accredited laboratory for chemical analysis.

Groundwater samples should be analysed for the chemical properties depicted below:

| | |
|---|---|
| Aluminium | Manganese |
| Ammonium | Nitrate ($NO_2$ and $NO_3$ as N) |
| Arsenic | pH at 25°C |

| | |
|---|---|
| Cadmium | Phosphate |
| Calcium | Potassium |
| Chloride | Silica |
| Chromium (Cr) | Sodium |
| Copper | Sulphate |
| E.Coli | Total Alkalinity (P and M) |
| Electrical Conductivity at 25°C (EC) | Total Coliforms |
| Fluoride | Total Dissolved Solids (TDS) |
| Hexavalent Chromium (Cr(IV)) | Total Hardness |
| Iron | Turbidity |
| Lead | Zinc |
| Magnesium | E-Coli / Total Coliforms |

The water quality results will be compared to the South African Water Quality Guidelines (SANS 241:2015) and water quality sampling and analyses to be undertaken monthly at the points indicated in Table 13-1. The reporting should be done quarterly and submitted to the DWS provincial head.

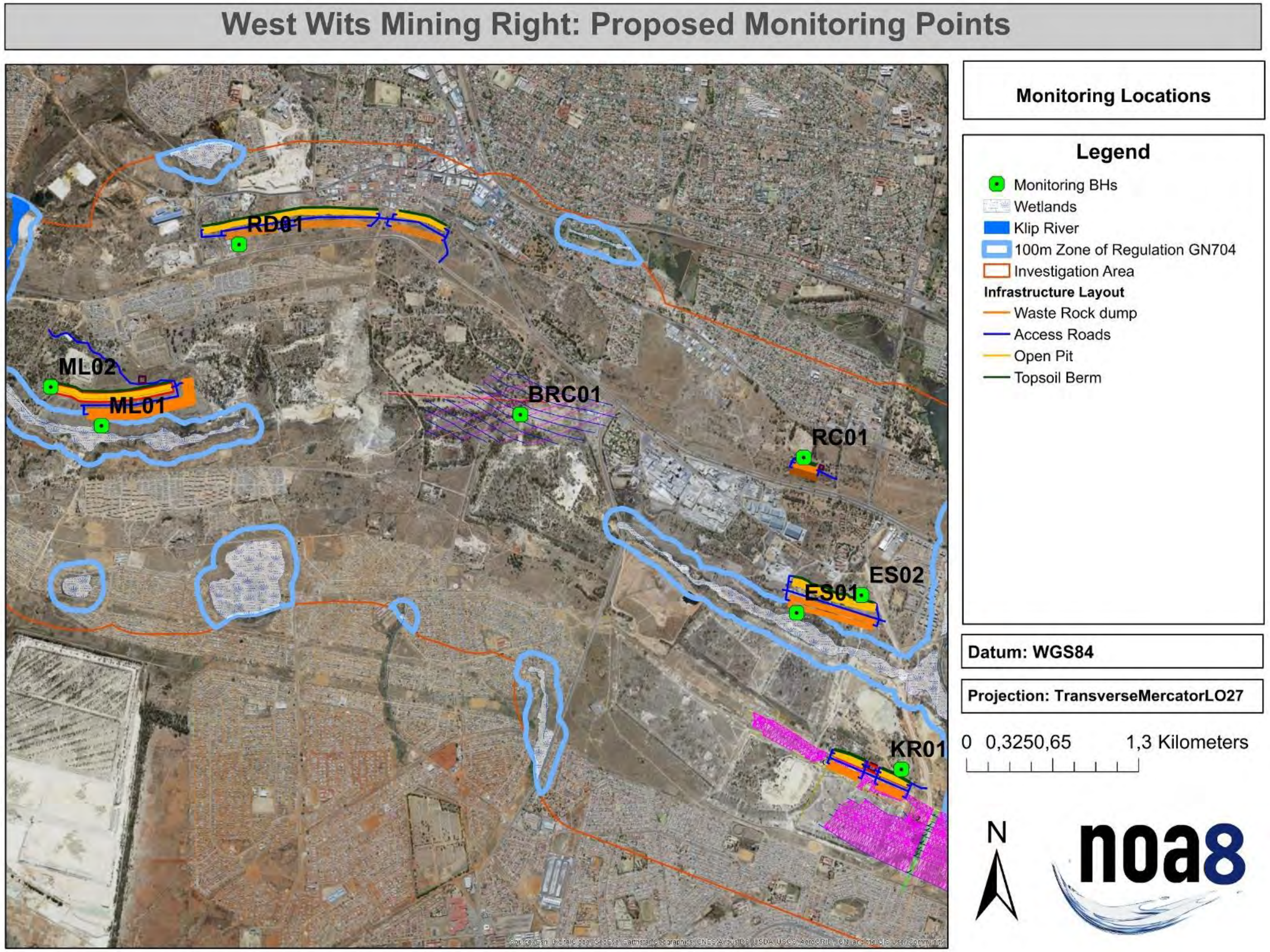


Figure 14-1 Poposed monitoring locations

# 15 References


1. Department of Water Affairs and Forestry, December 2006. Groundwater Assessment: Dolomite Aquifers. DWAF Report Number: P RSA C000/00/4406/06.
2. Department of Water Affairs and Forestry, December 2006. Vaal River System: Large Bulk Water Supply Reconciliation Strategy: Groundwater Assessment: Dolomite Aquifers.
3. Department of Water and Sanitation, April 2018. National Groundwater Archive data extraction.
4. GeoDyn Systems (Pty) Ltd, Geochemical Assessment for the proposed West Wits Mining Project, R N Hansen. 02 May 2019
5. Inter-Ministerial Committee, December 2010. Mine Water Management in the Witwatersrand Goldfields with special emphasis on Acid Mine Drainage. Under the Coordination of the Council for Geoscience.
6. SLR Consulting, December 2018. Scoping Report for the proposed West Wits Mining Project. SLR Project No.: 720.13087.00001
7. South African Bureau of Standards, 2015. South African National Standard. Drinking water. Part 1: Microbiological, physical, aesthetic and chemical determinants.
8. West Wits MLI (Pty) Ltd, 2018. Mining Work Programme.
9. www.reservoir.co.za/forums/vaalbarrage/klipriver_forum/klip_home.htm, April 2018. Klip River Water Quality Objectives.

# 16 Appendix A: Hydrocensus Data

Table 16-1 Hydrocensus data (1 of 2)

| Number | Lat | Long | Waterlevel (mbcl) | Collar height | Access | Date drilled | Depth | Type of pump | Yield | To where pump? | Size of reservoir | Pumping hours/day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WITBH 1 | -26.18319 | 27.85684 | 36.215 | 0.49 | | Not Known | 60 | Submersible | Not known | None | | 0 |
| WITStream 1 | -26.17845 | 27.83636 | | | Stream | N/A | | | | | N/A | |
| WITBH 2 | -26.17559 | 27.86703 | | -0.5 | Pump closed under rocks and sand | Not Known | 120 | Submersible | 1000 l/20min | To Tank | 5000 | 1 |
| WITBH 3 | -26.1709 | 27.82188 | | 0 | Closed up for theft | Not Known | 33 | Submersible | Not known | To Tank | 5000 | 7 |
| WITStream 2 | -26.16916 | 27.8336 | | | Stream | N/A | N/A | | | | | |
| WITBH 4 | -26.16607 | 27.87327 | 11.9 | -0.32 | | Not Known | Not Known | Submersible | Not known | To Tank | 5000 | Not Known |
| WITStream 3 | -26.19532 | 27.90214 | | | Stream | N/A | | | | | | |
| WITStream 4 | -26.19361 | 27.8976 | | | | N/A | | | | | | |
| WITBH 5 | -26.17104 | 27.88611 | 7.7 | 0.25 | | Not Known | Not Known | Windpump | | Not working | | None |
| WITBH 6 | -26.17184 | 27.88884 | 4.46 | -0.1 | | Not Known | Not Known | Submersible | Not known | Direct to irrigation | | 1 |

Table 16-2 Hydrocensus data (2 of 2)

| Number | Lat | Long | Discharge Pipe mm | Water use | Comments | Name or Address | Contact Name | Tel nr. | Sample Taken | Type | Time | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WITBH 1 | -26.18319 | 27.85684 | 0 | No pump equipped,45m water strike | Open well, recently drilled for future use | Blueprint | Mr A Cronje | | Yes | Bailed | 10:29 | 26-Mar-18 |
| WITStream 1 | -26.17845 | 27.83636 | | None | Stream on Eastern side of Mona Lisa, Stream flowing West | | | | Yes | Surface | 11:42 | 26-Mar-18 |
| WITBH 2 | -26.17559 | 27.86703 | 40 | Toilets at Golf club. | Hole pump for 20min, wait for 1 hour to recharge, pump again for 20mins | Durban Deep Golf Course | Mark Anthony ( Manager ) | 0817208785 | Yes | Pumped | 09:20 | 27-Mar-18 |
| WITBH 3 | -26.1709 | 27.82188 | 40 | Domestic and Swimming pool | Not using Municipal at all | 17 Mosega Street, Witpoortjie | Mr J H W Pretorius | 0834872404 | Yes | Pumped | 10:40 | 27-Mar-18 |
| WITStream 2 | -26.16916 | 27.8336 | | None | Stream on Most Western point of Zamma Zamma Mining from Mona Lisa | | | | Yes | Surface | 11:33 | 27-Mar-18 |
| WITBH 4 | -26.16607 | 27.87327 | | Domestic | Owner did not want to give out any info | Boroko Guest House 36 Olivier Street | Mr Sam Mohlakeng | 0823949773 | Yes | Pumped | 14:19 | 27-Mar-18 |
| WITStream 3 | -26.19532 | 27.90214 | | None | Stream to the Eastern side of Kimberley and 11 Shaft, stream flowing East | | | | Yes | Surface | 09:43 | 28-Mar-18 |
| WITStream 4 | -26.19361 | 27.8976 | | None | Stream on Western side of 11 Shaft | | | | Yes | Surface | 10:16 | 28-Mar-18 |
| WITBH 5 | -26.17104 | 27.88611 | | None | Pump broke in 2000, not used since | 3 Welbach Street, Hamberg | Mr N J Davids | 0114720604 | Yes | Bailed | 14:07 | 28-Mar-18 |
| WITBH 6 | -26.17184 | 27.88884 | | Only for garden | Brownish water, says it clears up after a while | 11 Hamman Street | Mr A C Gregory | 0738660828 | Yes | Pumped | 15:00 | 28-Mar-18 |

Table 16-3 Hydrocensus sampled sites field measurements

| Sample Point | pH | EC | TDS | Temp | Time | Date |
|---|---|---|---|---|---|---|
| BH 1 | 4.58 | 1000 | 540 | 19.9 | 10:29 | 26 March 2018 |
| Stream 1 | 5.35 | 663 | 356 | 19.3 | 11:42 | 26 March 2018 |
| BH 2 | 6.6 | 775 | 417 | 16.9 | 09:20 | 27 March 2018 |
| BH 3 | 6.22 | 98 | 51 | 20.5 | 10:40 | 27 March 2018 |
| Stream 2 | 6.33 | 237 | 127 | 18 | 11:35 | 27 March 2018 |
| BH 4 | 6.47 | 156 | 83 | 22.7 | 14:25 | 27 March 2018 |
| Stream 3 | 4.82 | 1653 | 895 | 17 | 09:49 | 28 March 2018 |
| Stream 4 | 4.32 | 567 | 846 | 19.3 | 10:18 | 28 March 2018 |
| BH 5 | 5.6 | 71 | 37 | 22 | 14:08 | 28 March 2018 |
| BH 6 | 6.18 | 341 | 183 | 22.2 | 15:00 | 28 March 2018 |

Table 16-4 Hydrocensus recorded sites: No access to boreholes

| Name | S | E | | Street Address | Comments |
|---|---|---|---|---|---|
| Private | -26.16608 | 27.82235 | Borehole | Plot 36 Reyger Street | Windpump, nobody home |
| UMC 12 | -26.16263 | 27.84549 | Mon Well | North of Piki Tup Penny Road | Well locked with padlock, no water level |
| Laerskool Die Ruiter | -26.17012 | 27.88294 | Borehole | Cnr Albert Sisulu and Lyon Street, Roodepoort | Principal has left for holiday, can make appointment 10th of April |
| Rolbal Club | 26.16717 | 27.87951 | Borehole | Tornado Crescent, Roodepoort | Closed, no answer at intercom gate |
| Hope Restoration Ministries | -26.17142 | 27.88522 | Borehole | Albert Sisulu Road next to Die Ruiter | Gardener said he's not allowed to open gate, can make appointment 30th March |
| Private | -26.17435 | 27.89256 | Borehole | 13 Flamingo Street, Roodepoort | Nobody at home |
| Afrisam | -26.17732 | 27.87931 | Borehole | Main Reef Road | Neels Venter, on leave for long weekend, contact him on 3rd April, Phone 011758600, Aquatico is doing monthly monitoring on Site. |

Table 16-5 Hydrocensus sites visited with no boreholes use

| Points | Address | Date and time | Lat | Long |
|---|---|---|---|---|
| 1 | 1 Berg Street | 2018/03/28 15:11 | -26.16673 | 27.88733 |
| 2 | 1 Mosega Street | 2018/03/27 10:53 | -26.17194 | 27.82014 |
| 3 | 10 Redshank Street | 2018/03/29 08:32 | -26.17363 | 27.89626 |
| 4 | 10 Smal Street | 2018/03/27 13:43 | -26.16354 | 27.86512 |
| 5 | 11 Roode Street | 13:14 28/3/18 Townhouse Complex | -26.17372 | 27.88016 |
| 6 | 1178 Wildplum Road | 2018/03/29 10:19 | -26.1875 | 27.90253 |
| 7 | 13 Bree Street | 2018/03/28 15:04 | -26.16948 | 27.88858 |
| 8 | 135 Hamberg Road | 2018/03/29 09:21 | -26.17732 | 27.89354 |
| 9 | 137 6th Street | 2018/03/27 15:22 | -26.16181 | 27.8803 |
| 10 | 137 Jood Street | 2018/03/28 11:12 | -26.16879 | 27.85384 |
| 11 | 14 Kent Street | 2018/03/28 11:49 | -26.16743 | 27.88236 |
| 12 | 140 Maynier Street | 201-03-27 11:26:00 AM | -26.16773 | 27.82605 |
| 13 | 15035 Baloon Street | 2018/03/26 11:11 | -26.18428 | 27.83249 |
| 14 | 15395 Alpine Street | 2018/03/26 11:45 | -26.18544 | 27.83482 |
| 15 | 15421 Cnr Tadore Cr and Alpine Street | 2018/03/26 11:15 | -26.18469 | 27.83348 |
| 16 | 155 Hamberg Road | 2018/03/29 09:24 | -26.17837 | 27.89565 |
| 17 | 159 Breda Street | 2018/03/27 11:20 | -26.16803 | 27.82831 |
| 18 | 16 Fearick Street | 2018/03/27 13:08 | -26.15868 | 27.8518 |
| 19 | 16 Mare Street | 13:33 27/3/18 Samatarian Ministries | -26.16302 | 27.85873 |
| 20 | 1633 Plumbaco Street | 2018/03/29 10:34 | -26.1877 | 27.90277 |
| 21 | 167 Makwathasa | 2018/03/26 11:05 | -26.18273 | 27.839 |
| 22 | 17 Riethaan Street | 2018/03/28 15:27 | -26.17076 | 27.89675 |
| 23 | 17 Widgeon Street | 2018/03/29 08:42 | -26.17638 | 27.89624 |
| 24 | 1739 Fever Tree Road | 2018/03/29 10:23 | -26.18869 | 27.90497 |
| 25 | 19 Welbach Street | 2018/03/28 14:24 | -26.17307 | 27.88899 |
| 26 | 198 Reyger Street | 2018/03/27 11:08 | -26.1658 | 27.83185 |
| 27 | 20 Cygnet Street | 2018/03/29 08:35 | -26.17529 | 27.89803 |
| 28 | 20 Makou Street | 2018/03/29 08:20 | -26.17404 | 27.89898 |
| 29 | 21 Hamman Street | 2018/03/28 14:27 | -26.17262 | 27.88944 |
| 30 | 21 Outcrop Crescent | 2018/03/28 13:24 | -26.16912 | 27.87866 |
| 31 | 24 Lepelaar Street | 2018/03/29 08:53 | -26.17435 | 27.89374 |
| 32 | 24 Nantes Street | 2018/03/27 10:58 | -26.16959 | 27.82084 |
| 33 | 25 Chake Street | 2018/03/29 09:11 | -26.17231 | 27.89263 |
| 34 | 25 Dabchick Street | 2018/03/28 15:55 | -26.17396 | 27.90042 |
| 35 | 25 Kemphaan Street | 2018/03/29 09:01 | -26.17574 | 27.89286 |
| 36 | 26 Green Street | 2018/03/28 11:08 | -26.16861 | 27.85563 |
| 37 | 29 Wandel Street | 2018/03/28 15:06 | -26.16975 | 27.89048 |
| 38 | 3 Lawa Street | 2018/03/28 13:17 | -26.1718 | 27.88081 |
| 39 | 3 Magnesium Ave | 2018/03/28 12:21 | -26.17426 | 27.88072 |
| 40 | 302 Clubhouse Street | 2018/03/28 10:56 | -26.16993 | 27.85703 |
| 41 | 323 Chip Crescent | 2018/03/28 11:15 | -26.16896 | 27.85502 |

| Points | Address | Date and time | Lat | Long |
|---|---|---|---|---|
| 42 | 340 Fairway Drive | 2018/03/28 11:02 | -26.16809 | 27.86168 |
| 43 | 346 Sophocles Street | 2018/03/27 12:55 | -26.15869 | 27.84701 |
| 44 | 363 Sophocles Street | 2018/03/27 12:57 | -26.15852 | 27.848 |
| 45 | 371 Cnr Fairway and Club House Street | 2018/03/28 11:06 | -26.16737 | 27.85714 |
| 46 | 371 Rough Street | 2018/03/28 11:18 | -26.1699 | 27.85507 |
| 47 | 4 Coot Street | 2018/03/29 08:58 | -26.17478 | 27.89126 |
| 48 | 4 Dabchick Street | 2018/03/28 15:30 | -26.1714 | 27.89493 |
| 49 | 4 Grens Hudson Street | 2018/03/27 14:56 | -26.16479 | 27.8747 |
| 50 | 4 Potgieter Road | 2018/03/29 08:56 | -26.17379 | 27.89033 |
| 51 | 40 7th Street | 2018/03/27 15:14 | -26.15702 | 27.872 |
| 52 | 405 Caddie Street | 2018/03/28 11:22 | -26.16951 | 27.85908 |
| 53 | 41 Cygnet Street | 2018/03/29 08:38 | -26.17606 | 27.90011 |
| 54 | 42 Dabchick Street | 2018/03/28 15:33 | -26.17322 | 27.89938 |
| 55 | 43 Berg Street | 2018/03/28 15:14 | -26.16766 | 27.89227 |
| 56 | 45 1St Avenue | 2018/03/27 15:01 | -26.1635 | 27.87439 |
| 57 | 49 6th Street | 2018/03/27 15:17 | -26.15863 | 27.87362 |
| 58 | 49 Tornado Crescent | 2018/03/28 01:55 | -26.1683 | 27.88011 |
| 59 | 5 Duiker Street | 2018/03/29 08:50 | -26.176 | 27.89534 |
| 60 | 5 Egret Street | 2018/03/29 08:47 | -26.17631 | 27.89481 |
| 61 | 5 Marechale Street | 2018/03/27 10:56 | -26.17103 | 27.82022 |
| 62 | 5 Shelde Street | 2018/03/27 11:17 | -26.16763 | 27.8295 |
| 63 | 520 Reyger Street | 2018/03/27 11:10 | -26.16652 | 27.8317 |
| 64 | 54 Kemphaan Street | 2018/03/29 08:44 | -26.17758 | 27.89535 |
| 65 | 57 Riethaan Street | 2018/03/28 15:24 | -26.171 | 27.90061 |
| 66 | 593 Cupido Cresent | 2018/03/27 13:11 | -26.15912 | 27.85357 |
| 67 | 6 Outcrop Cresent | 2018/03/28 13:26 | -26.17031 | 27.87982 |
| 68 | 6 Schrikker Street | 2018/03/27 13:16 | -26.16043 | 27.852 |
| 69 | 6 Slate Street | 2018/03/28 13:19 | -26.17133 | 27.88124 |
| 70 | 60 Spoorweg Street | 2018/03/27 14:52 | -26.16357 | 27.87337 |
| 71 | 616 Oliphant Street | 2018/03/27 13:13 | -26.15826 | 27.85274 |
| 72 | 644 Leadwood Street | 2018/03/29 10:42 | -26.19394 | 27.90903 |
| 73 | 669 Leadwood Street | 2018/03/29 10:40 | -26.19296 | 27.90695 |
| 74 | 67 1St Avenue | 2018/03/27 15:05 | -26.16316 | 27.87659 |
| 75 | 7 Barrie Street | 2018/03/28 15:02 | -26.16915 | 27.88661 |
| 76 | 7 Eider Street | 2018/03/02 09:15 | -26.17232 | 27.89479 |
| 77 | 7 Mcartney Street | 2018/03/27 11:14 | -26.1674 | 27.83048 |
| 78 | 7 Platinum Street | 2018/03/28 13:16 | -26.17299 | 27.88096 |
| 79 | 718 Sweet Thorn Street | 2018/03/29 10:55 | -26.19101 | 27.90803 |
| 80 | 75 Potassium Ave | 2018/03/28 13:09 | -26.17373 | 27.8769 |
| 81 | 843 Yellowood Street | 2018/03/29 10:48 | -26.1893 | 27.90859 |
| 82 | 85 Potassium Ave | 2018/03/28 13:07 | -26.17274 | 27.87549 |
| 83 | 9 Geoffrey Street | 2018/03/27 14:44 | -26.1653 | 27.87117 |
| 84 | 918 Shakespear Close | 2018/03/26 13:01 | -26.16228 | 27.83422 |
| 85 | 926 Shekespear Close | 2018/03/26 12:57 | -26.16432 | 27.8338 |

| Points | Address | Date and time | Lat | Long |
|---|---|---|---|---|
| 86 | 934 Shakespear Close | 2018/03/26 12:59 | -26.16344 | 27.83395 |
| 87 | 950 Salinga Cresent | 2018/03/29 10:52 | -26.18802 | 27.90775 |
| 88 | ANSEC | 11:57 27/03/18 big new development new subur | -26.1635 | 27.84483 |
| 89 | Auto Wreck Motor Scrapyard | 13:25 27/3/18 1 van wyk Street | -26.6312 | 27.85038 |
| 90 | Brick Factory | 2018/03/27 11:50 | -26.16638 | 27.8486 |
| 91 | Bumpers and Scrapyard | 2018/03/29 12:00 | -26.17732 | 27.87931 |
| 92 | City Road Board | 2018/03/29 09:31 | -26.17783 | 27.89837 |
| 93 | Claw | 9:36 27/3/18 Community Led Animal Welfare | -26.1717 | 27.86238 |
| 94 | Clinic | 2018/03/26 10:50 | -26.18393 | 27.8408 |
| 95 | Epic Estate Calvinia Street | 2018/03/27 11:22 | -26.16802 | 27.82543 |
| 96 | Forandia Park Townhouses | 2018/03/29 08:29 | -26.17352 | 27.89767 |
| 97 | House 445 Leratong Village | 2018/03/27 10:01 | -26.18095 | 27.81517 |
| 98 | House 504 Leratong Village | 2018/03/27 10:00 | -26.18006 | 27.81543 |
| 99 | Infrastructure Specialist Group (ISG) | 11:29 29/3/18 Cnr Main Reef and Houtkapper Road. Director on leave till 3rd of April 0116746900 | -26.18141 | 27.8882 |
| 100 | ISA Outreach Kent Street | 2018/03/28 11:52 | -26.16767 | 27.88087 |
| 101 | Julius Auto Scrapyard | 13:28 27/3/18 Nick Toomay Bldv | -26.16668 | 27.8492 |
| 102 | Kidbrook Uraan Road | 2018/03/28 13:29 | -26.1708 | 27.88182 |
| 103 | Leratong Village Randwater Park and Play | 2018/03/27 09:51 | -26.1781 | 27.815 |
| 104 | Little Flowers Daycare Potassium Ave | 2018/03/28 13:12 | -26.17448 | 27.87817 |
| 105 | Maxam Africa Mine | 10:12 29/3/18 Morne 0832586361 | -26.19958 | 27.8963 |
| 106 | Maxam Projects Office | 10:02 29/3/18 Houtkapper road | -26.18691 | 27.89758 |
| 107 | Merco Industries | 14:39 27/3/18 46 geoffry Street | -26.16699 | 27.87359 |
| 108 | Mlilo Projects | 2018/03/29 09:47 | -26.18753 | 27.89795 |
| 109 | Oil Pit | 28/3/18 Hole dug with old used oil in it . close to Wit Potch Village, Zamma Zammas Mining in the area | -26.17339 | 27.84084 |
| 110 | Platinum Int Training College | 13:36 27/3/18 11 Goud street | -26.16365 | 27.86203 |
| 111 | Potgieter Street | 15:17 28/3/18 Theronia Complex | -26.16905 | 27.89415 |
| 112 | Renuco Construction | 11:23 29/3/18 Andre said no Boreholes 0827100060 | -26.18244 | 27.89214 |
| 113 | Roodepark Sports Fields | 15:20 28/3/18 Potgieter Street, Closed | -26.16858 | 27.89471 |
| 114 | Roodepoort Health Care Risk Waste Treatment Facility | 2018/03/29 09:40 | -26.18044 | 27.89266 |
| 115 | Roodepoort North APK Church | 2018/03/27 15:10 | -26.16068 | 27.8749 |
| 116 | Roodepoort Primary School | 13:00 27/3/18 Manual Street | -26.15699 | 27.85146 |
| 117 | Roodepoort Rugby Club | 12:14 28/3/18 Closed down | -26.17872 | 27.89385 |
| 118 | Sach Warr Engineering | 2018/03/27 13:21 | -26.16456 | 27.85154 |
| 119 | Solplaatjie Community Centre | 10:47 26/03/18 cnr West End and Nic Toomey Blvd | -26.18246 | 27.85427 |
| 120 | Tornado Park Retirement Village | 15:07 27/3/18 1St Avenue | -26.16215 | 27.87801 |
| 121 | Umfoleni Heights Flats Cnr Wild Olive and Fever Tree | 2018/03/29 10:26 | -26.18931 | 27.90472 |
| 122 | Upward Spiral | 12:23 26/3/18 No Access J Bezuidenhout 0822421849 | -26.17344 | 27.83989 |
| 123 | West rand K9 Unit | 2018/03/27 12:18 | -26.16371 | 27.8479 |
| 124 | Witpoortjie Estates | 13:04 Townhouse Complex | -26.17373 | 27.82482 |

# 17 Appendix B: Water quality certificates

Table 17-1 Water quality results: WestWits BH1 and Stream1

| Determinand | Units | Method No | Results | |
|---|---|---|---|---|
| | | | 004806/18 | 004807/18 |
| | | | WESTWITS WITBH 1 26.03.18 | WESTWITS WITSTREAM 1 26.03.18 |
| Ammonia | mg N/ℓ | 64G | 1.69 | 7.88 |
| Chloride | mg Cl/ℓ | 16G | 37 | 26 |
| Cyanide (Total)* | µg CN/ℓ | 206 | <10 | <10 |
| Dissolved Aluminium | mg Al/ℓ | 87 | 60 | 5.00 |
| Dissolved Antimony | mg Sb/ℓ | 89 | <0.009 | <0.009 |
| Dissolved Arsenic | mg As/ℓ | 88 | <0.04 | <0.04 |
| Dissolved Barium | mg Ba/ℓ | 87 | 0.02 | 0.03 |
| Dissolved Beryllium | mg Be/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Boron | mg B/ℓ | 87 | 0.13 | 0.11 |
| Dissolved Cadmium | mg Cd/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Calcium | mg Ca/ℓ | 85 | 228 | 147 |
| Dissolved Chromium | mg Cr/ℓ | 87 | 0.03 | <0.02 |
| Dissolved Cobalt | mg Co/ℓ | 87 | 1.45 | 0.63 |
| Dissolved Copper | mg Cu/ℓ | 87 | 0.70 | 0.06 |
| Dissolved Iron | mg Fe/ℓ | 87 | 0.07 | <0.02 |
| Dissolved Lead | mg Pb/ℓ | 87 | 0.06 | <0.03 |
| Dissolved Lithium | mg Li/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Magnesium | mg Mg/ℓ | 85 | 65 | 29 |
| Dissolved Manganese | mg Mn/ℓ | 87 | 9.25 | 4.78 |
| Dissolved Mercury | mg Hg/ℓ | 86 | <0.002 | <0.002 |
| Dissolved Molybdenum* | mg Mo/ℓ | 87 | <0.11 | <0.11 |
| Dissolved Nickel | mg Ni/ℓ | 87 | 2.16 | 1.72 |
| Dissolved Selenium | mg Se/ℓ | 88 | <0.07 | <0.07 |
| Dissolved Silver* | mg Ag/ℓ | 87 | <0.01 | <0.01 |
| Dissolved Strontium | mg Sr/ℓ | 87 | 0.43 | 0.19 |
| Dissolved Thallium | mg Tl/ℓ | 87 | 0.02 | <0.02 |
| Dissolved Tin | mg Sn/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Titanium | mg Ti/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Uranium* | mg U/ℓ | 87 | 0.49 | 0.17 |
| Dissolved Vanadium | mg V/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Zinc | mg Zn/ℓ | 87 | 2.69 | 0.86 |
| Dissolved Zirconium | mg Zr/ℓ | 87 | <0.02 | <0.02 |
| *E.coli* | colonies per 100mℓ | 31 | 0 | 0 |
| Electrical Conductivity at 25°C | mS/m | 2 | 187 | 103 |
| Fluoride | mg F/ℓ | 18G | <0.03 | <0.03 |
| Free Ammonia* | mg N/ℓ | Calc. | <0.11 | <0.11 |
| Saline Ammonia* | mg N/ℓ | Calc. | 1.69 | 7.88 |
| Nitrate | mg N/ℓ | 65Gc | 9.78 | 0.06 |
| Orthophosphate | mg P/ℓ | 66G | 0.06 | 0.84 |
| pH at 25°C | pH units | 1A | 3.4 | 4.5 |
| Potassium | mg K/ℓ | 85 | 13.0 | 7.23 |
| Sodium | mg Na/ℓ | 84 | 49 | 34 |
| Sulphate | mg $SO_4$/ℓ | 67G | 1 144 | 597 |
| Total Dissolved Solids* | Calc. | - | 1 249 | 684 |

Table 17-2 Water quality results: WestWits BH2 and BH3

| Determinand | Units | Method No | Results | |
|---|---|---|---|---|
| | | | 004808/18 | 004809/18 |
| | | | WESTWITS WITBH 2 26.03.18 | WESTWITS WITHBH 3 26.03.18 |
| Ammonia | mg N/ℓ | 64G | 0.24 | <0.11 |
| Chloride | mg Cl/ℓ | 16G | 36 | 12.6 |
| Cyanide (Total)* | µg CN/ℓ | 206 | <10 | <10 |
| Dissolved Aluminium | mg Al/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Antimony | mg Sb/ℓ | 89 | 0.01 | 0.01 |
| Dissolved Arsenic | mg As/ℓ | 88 | <0.04 | <0.04 |
| Dissolved Barium | mg Ba/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Beryllium | mg Be/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Boron | mg B/ℓ | 87 | 0.07 | 0.05 |
| Dissolved Cadmium | mg Cd/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Calcium | mg Ca/ℓ | 85 | 161 | 6.17 |
| Dissolved Chromium | mg Cr/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Cobalt | mg Co/ℓ | 87 | 0.06 | <0.02 |
| Dissolved Copper | mg Cu/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Iron | mg Fe/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Lead | mg Pb/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Lithium | mg Li/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Magnesium | mg Mg/ℓ | 85 | 82 | 5.93 |
| Dissolved Manganese | mg Mn/ℓ | 87 | 0.26 | <0.02 |
| Dissolved Mercury | mg Hg/ℓ | 86 | <0.01 | <0.01 |
| Dissolved Molybdenum* | mg Mo/ℓ | 87 | <0.11 | <0.11 |
| Dissolved Nickel | mg Ni/ℓ | 87 | 0.29 | <0.02 |
| Dissolved Selenium | mg Se/ℓ | 88 | <0.07 | <0.07 |
| Dissolved Silver* | mg Ag/ℓ | 87 | <0.01 | <0.01 |
| Dissolved Strontium | mg Sr/ℓ | 87 | 0.18 | 0.03 |
| Dissolved Thallium | mg Tl/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Tin | mg Sn/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Titanium | mg Ti/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Uranium* | mg U/ℓ | 87 | 0.06 | <0.02 |
| Dissolved Vanadium | mg V/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Zinc | mg Zn/ℓ | 87 | 7.69 | 0.25 |
| Dissolved Zirconium | mg Zr/ℓ | 87 | <0.02 | <0.02 |
| *E.coli* | colonies per 100mℓ | 31 | 0 | 46 |
| Electrical Conductivity at 25°C | mS/m | 2 | 132 | 12 |
| Fluoride | mg F/ℓ | 18G | 0.99 | 0.05 |
| Free Ammonia* | mg N/ℓ | Calc. | <0.11 | <0.11 |
| Saline Ammonia* | mg N/ℓ | Calc. | 0.24 | <0.11 |
| Nitrate | mg N/ℓ | 65Gc | 2.40 | 4.20 |
| Orthophosphate | mg P/ℓ | 66G | <0.04 | 0.15 |
| pH at 25°C | pH units | 1A | 6.6 | 6.4 |
| Potassium | mg K/ℓ | 85 | 7.06 | 0.46 |
| Sodium | mg Na/ℓ | 84 | 59 | 6.61 |
| Sulphate | mg $SO_4$/ℓ | 67G | 742 | <0.21 |
| Total Dissolved Solids* | Calc. | - | 878 | 78 |

Table 17-3 Water quality results: WestWits Stream 2 and BH4

| Determinand | Units | Method No | Results | |
|---|---|---|---|---|
| | | | 004810/18 | 004811/18 |
| | | | WESTWITS WITSTREAM 2 26.03.18 | WESTWITS WITBH 4 26.03.18 |
| Ammonia | mg N/ℓ | 64G | <0.11 | <0.11 |
| Chloride | mg Cl/ℓ | 16G | 19.8 | 16.7 |
| Cyanide (Total)* | µg CN/ℓ | 206 | <10 | <10 |
| Dissolved Aluminium | mg Al/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Antimony | mg Sb/ℓ | 89 | 0.01 | <0.009 |
| Dissolved Arsenic | mg As/ℓ | 88 | <0.04 | <0.04 |
| Dissolved Barium | mg Ba/ℓ | 87 | 0.02 | <0.02 |
| Dissolved Beryllium | mg Be/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Boron | mg B/ℓ | 87 | 0.07 | 0.03 |
| Dissolved Cadmium | mg Cd/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Calcium | mg Ca/ℓ | 85 | 34 | 7.94 |
| Dissolved Chromium | mg Cr/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Cobalt | mg Co/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Copper | mg Cu/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Iron | mg Fe/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Lead | mg Pb/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Lithium | mg Li/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Magnesium | mg Mg/ℓ | 85 | 11.0 | 14.9 |
| Dissolved Manganese | mg Mn/ℓ | 87 | 0.10 | 0.02 |
| Dissolved Mercury | mg Hg/ℓ | 86 | <0.002 | 0.003 |
| Dissolved Molybdenum* | mg Mo/ℓ | 87 | <0.11 | <0.11 |
| Dissolved Nickel | mg Ni/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Selenium | mg Se/ℓ | 88 | <0.07 | <0.07 |
| Dissolved Silver* | mg Ag/ℓ | 87 | <0.01 | <0.01 |
| Dissolved Strontium | mg Sr/ℓ | 87 | 0.11 | 0.05 |
| Dissolved Thallium | mg Tl/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Tin | mg Sn/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Titanium | mg Ti/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Uranium* | mg U/ℓ | 87 | 0.03 | <0.02 |
| Dissolved Vanadium | mg V/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Zinc | mg Zn/ℓ | 87 | 0.19 | 0.05 |
| Dissolved Zirconium | mg Zr/ℓ | 87 | <0.02 | <0.02 |
| *E.coli* | colonies per 100mℓ | 31 | 50 | 540 |
| Electrical Conductivity at 25°C | mS/m | 2 | 32 | 19 |
| Fluoride | mg F/ℓ | 18G | 0.10 | 0.09 |
| Free Ammonia* | mg N/ℓ | Calc. | <0.11 | <0.11 |
| Saline Ammonia* | mg N/ℓ | Calc. | <0.11 | <0.11 |
| Nitrate | mg N/ℓ | 65Gc | 1.30 | 12.6 |
| Orthophosphate | mg P/ℓ | 66G | <0.04 | 0.11 |
| pH at 25°C | pH units | 1A | 7.0 | 7.0 |
| Potassium | mg K/ℓ | 85 | 5.47 | 0.91 |
| Sodium | mg Na/ℓ | 84 | 21 | 4.83 |
| Sulphate | mg $SO_4$/ℓ | 67G | 83 | 2.02 |
| Total Dissolved Solids* | Calc. | - | 217 | 126 |

Table 17-4 Water quality results: WestWits Stream 3 and Stream 4

| Determinand | Units | Method No | Results | |
|---|---|---|---|---|
| | | | 004812/18 | 004813/18 |
| | | | WESTWITS WITSTREAM 3 26.03.18 | WESTWITS WITSTREAM 4 26.03.18 |
| Ammonia | mg N/ℓ | 64G | 48 | 15.3 |
| Chloride | mg Cl/ℓ | 16G | 227 | 249 |
| Cyanide (Total)* | µg CN/ℓ | 206 | <10 | <10 |
| Dissolved Aluminium | mg Al/ℓ | 87 | 11.4 | 14.0 |
| Dissolved Antimony | mg Sb/ℓ | 89 | <0.009 | 0.02 |
| Dissolved Arsenic | mg As/ℓ | 88 | <0.04 | <0.04 |
| Dissolved Barium | mg Ba/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Beryllium | mg Be/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Boron | mg B/ℓ | 87 | 0.34 | 0.31 |
| Dissolved Cadmium | mg Cd/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Calcium | mg Ca/ℓ | 85 | 365 | 345 |
| Dissolved Chromium | mg Cr/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Cobalt | mg Co/ℓ | 87 | 0.91 | 0.92 |
| Dissolved Copper | mg Cu/ℓ | 87 | 0.17 | 0.13 |
| Dissolved Iron | mg Fe/ℓ | 87 | 1.46 | 1.88 |
| Dissolved Lead | mg Pb/ℓ | 87 | 0.04 | 0.06 |
| Dissolved Lithium | mg Li/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Magnesium | mg Mg/ℓ | 85 | 84 | 85 |
| Dissolved Manganese | mg Mn/ℓ | 87 | 18.1 | 29 |
| Dissolved Mercury | mg Hg/ℓ | 86 | <0.002 | <0.002 |
| Dissolved Molybdenum* | mg Mo/ℓ | 87 | <0.11 | <0.11 |
| Dissolved Nickel | mg Ni/ℓ | 87 | 1.35 | 1.28 |
| Dissolved Selenium | mg Se/ℓ | 88 | <0.07 | <0.07 |
| Dissolved Silver* | mg Ag/ℓ | 87 | <0.01 | <0.01 |
| Dissolved Strontium | mg Sr/ℓ | 87 | 0.79 | 0.72 |
| Dissolved Thallium | mg Tl/ℓ | 87 | 0.02 | 0.03 |
| Dissolved Tin | mg Sn/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Titanium | mg Ti/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Uranium* | mg U/ℓ | 87 | 0.13 | 0.05 |
| Dissolved Vanadium | mg V/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Zinc | mg Zn/ℓ | 87 | 2.32 | 2.08 |
| Dissolved Zirconium | mg Zr/ℓ | 87 | <0.02 | <0.02 |
| *E.coli* | colonies per 100mℓ | 31 | 0 | 0 |
| Electrical Conductivity at 25°C | mS/m | 2 | 306 | 293 |
| Fluoride | mg F/ℓ | 18G | <0.03 | <0.03 |
| Free Ammonia* | mg N/ℓ | Calc. | <0.11 | <0.11 |
| Saline Ammonia* | mg N/ℓ | Calc. | 48 | 15.3 |
| Nitrate | mg N/ℓ | 65Gc | 32 | 2.20 |
| Orthophosphate | mg P/ℓ | 66G | 0.77 | <0.04 |
| pH at 25°C | pH units | 1A | 3.4 | 3.3 |
| Potassium | mg K/ℓ | 85 | 90 | 98 |
| Sodium | mg Na/ℓ | 84 | 175 | 186 |
| Sulphate | mg $SO_4$/ℓ | 67G | 1 392 | 1 322 |
| Total Dissolved Solids* | Calc. | - | 2 041 | 1 954 |

Table 17-5 Water quality results: WestWits BH5 and BH6

| Determinand | Units | Method No | Results | |
|---|---|---|---|---|
| | | | 004814/18 | 004815/18 |
| | | | WESTWITS WITBH 5 26.03.18 | WESTWITS WITBH 6 26.03.18 |
| Ammonia | mg N/ℓ | 64G | 0.31 | <0.11 |
| Chloride | mg Cl/ℓ | 16G | 3.78 | 28 |
| Cyanide (Total)* | µg CN/ℓ | 206 | <10 | <10 |
| Dissolved Aluminium | mg Al/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Antimony | mg Sb/ℓ | 89 | 0.01 | <0.009 |
| Dissolved Arsenic | mg As/ℓ | 88 | <0.04 | <0.04 |
| Dissolved Barium | mg Ba/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Beryllium | mg Be/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Boron | mg B/ℓ | 87 | 0.03 | 0.04 |
| Dissolved Cadmium | mg Cd/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Calcium | mg Ca/ℓ | 85 | 7.15 | 69 |
| Dissolved Chromium | mg Cr/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Cobalt | mg Co/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Copper | mg Cu/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Iron | mg Fe/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Lead | mg Pb/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Lithium | mg Li/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Magnesium | mg Mg/ℓ | 85 | 1.71 | 18.6 |
| Dissolved Manganese | mg Mn/ℓ | 87 | 0.12 | <0.02 |
| Dissolved Mercury | mg Hg/ℓ | 86 | 0.003 | <0.002 |
| Dissolved Molybdenum* | mg Mo/ℓ | 87 | <0.11 | <0.11 |
| Dissolved Nickel | mg Ni/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Selenium | mg Se/ℓ | 88 | <0.07 | <0.07 |
| Dissolved Silver* | mg Ag/ℓ | 87 | <0.01 | <0.01 |
| Dissolved Strontium | mg Sr/ℓ | 87 | 0.02 | 0.31 |
| Dissolved Thallium | mg Tl/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Tin | mg Sn/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Titanium | mg Ti/ℓ | 87 | <0.03 | <0.03 |
| Dissolved Uranium* | mg U/ℓ | 87 | <0.02 | 0.04 |
| Dissolved Vanadium | mg V/ℓ | 87 | <0.02 | <0.02 |
| Dissolved Zinc | mg Zn/ℓ | 87 | 1.17 | 0.16 |
| Dissolved Zirconium | mg Zr/ℓ | 87 | <0.02 | <0.02 |
| *E.coli* | colonies per 100mℓ | 31 | 0 | 0 |
| Electrical Conductivity at 25°C | mS/m | 2 | 10 | 50 |
| Fluoride | mg F/ℓ | 18G | 0.21 | 0.13 |
| Free Ammonia* | mg N/ℓ | Calc. | <0.11 | <0.11 |
| Saline Ammonia* | mg N/ℓ | Calc. | 0.31 | <0.11 |
| Nitrate | mg N/ℓ | 65Gc | 0.77 | 10.0 |
| Orthophosphate | mg P/ℓ | 66G | 0.66 | 0.04 |
| pH at 25°C | pH units | 1A | 6.5 | 6.9 |
| Potassium | mg K/ℓ | 85 | 8.79 | 2.19 |
| Sodium | mg Na/ℓ | 84 | 6.61 | 20 |
| Sulphate | mg $SO_4$/ℓ | 67G | 8.40 | 74 |
| Total Dissolved Solids* | Calc. | - | 65 | 332 |

# 18 Appendix C: Specialist CV

## Curriculum Vitae
## Willem Johannes Meyer
## (Hydrogeologist)

| | | | |
|---|---|---|---|
| **Full Name:** | Willem Johannes Meyer | English Fluency: | Excellent |
| **Discipline:** | Hydrogeologist | Nationality: | South African |
| **Education:** | B.Sc. Honors | Age: | 35 |
| **Project Position:** | Hydrogeologist | Years' experience: | 12 |

| School | Date of Attendance | Degree/Certification |
|---|---|---|
| University of the Free State | 2008 | B.Sc. Honors Geohydrology |
| University of Pretoria | 2007 | BSc Environmental and Engineering Geology |

**Major Subjects**

Geophysics, Aquifer Hydraulics, Groundwater Flow Modelling, Groundwater Chemistry and Management.

**Certificates and courses:**

2010: Feflow Advanced Groundwater Flow Modelling (Berlin, Germany)
2012: Mike SHE Surface Water Modelling (Johannesburg, South Africa)

**Professional affiliation:**

Groundwater Division of the Geological Society of South Africa.
SACNASP: Pr. Sci. Nat

**Career highlights:**

- WJ Meyer is a hydrogeologist with 10 years' experience. He has an honors degree in hydrogeology (University of the Free State).

**Experience:**

| **Position:** | **Hydrogeologist** | **Duration:** | **10 years** |
|---|---|---|---|

**Date of employment:** November 2007 to March 2017

**Employer:**

Exigo Sustainability (Pty) Ltd, South Africa

**Type of Projects:**

Geohydrological consulting with focus on detailed numerical modelling

**Scope of Employer's Contract:**

Responsibilities include amongst other marketing, scoping and successfully completion of projects, project development and management, with a focus on numerical groundwater flow modelling (Feflow).

| **Position:** | **Hydrogeologist** | **Duration:** | **6 months** |
|---|---|---|---|

**Date of employment:** April 2017

**Employer:**

Noa Agencies (Pty) Ltd

**Type of Projects:**

Numerical Groundwater Flow Modelling, water and monitoring management and dewatering implementation

**Scope of Employer's Contract:**

Detail numerical groundwater flow models with a focus on dewatering design, implementation and commissioning. Groundwater and water management review and implementation.

**Key professional characteristics and trades:**

Analytical and Strategic/Environmental thinking and decision making

Analytical groundwater balances and aquifer sustainability and conceptual models

Characterization of aquifers with a focus on management of regional groundwater systems.

Data capturing, database development and management.

Data evaluation and interpretations

Environmental geohydrological impact and risk assessments.

Environmental monitoring and development of monitoring protocol.

Evaluation of groundwater specialist studies in the mining industry, which includes water supply, mine dewatering design and groundwater pollution. Experience in PFS and DFS.

Groundwater flow and contaminant transport modelling. Statistical modelling for water supply assurance levels, risk assessments, dewatering design and contaminant transport

Groundwater management for water supply and environmental management programmes (EMP's).

Borehole drilling supervision and design (water supply, dewatering and monitoring boreholes).

Aquifer testing design and implementation: packer testing, constant discharge, falling head tests and constant head tests.

Mine groundwater inflow and dewatering design.

**Selected Project Experience:**

Nokeng Fluorspar Water Supply, Numerical Modelling and Dewatering Design

Kenya Fluorspar Dewatering Assessment

KCC KOV & Kamoto Underground Dewatering Phase 1

Musonoi Detailed Dewatering Assessment: Numerical Modelling

Kisanfu Copper Mine: Detailed Mine Dewatering Design

Platmin Sedibelo Rural Water Supply

Platmin Update of Hydrogeological Specialist Study

SLR Otjikoto Mine Dewatering

Lonmin Regional Water Supply

KML KOV Piezometer Installation and Packer Testing Supervision

Skorpion Zinc Hydrogeological Specialist Study