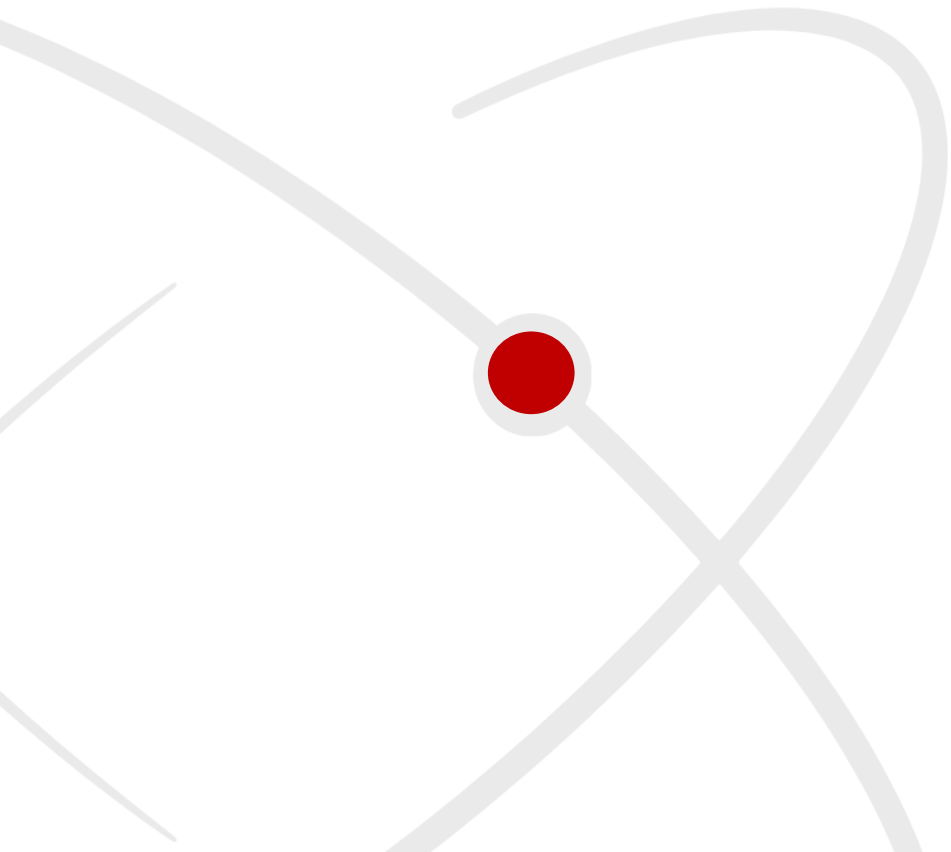
arp | CONSULTING

AQUISIM RADIOLOGICAL PROTECTION

Radiological Public Safety Assessment for the Harmony West Wits Reclamation and Deposition Project and Associated Infrastructure



Report No. ARP-1008A

August 2026

DISCLAIMER

Although due care and diligence were exercised in rendering services and preparing documents, AquiSim Consulting (Pty) Ltd accepts no liability. The client, by receiving this document, indemnifies AquiSim Consulting (Pty) Ltd and its directors, managers, agents and employees against all actions, claims, demands, losses, liabilities, costs, damages, and expenses arising from or in connection with services rendered, directly or indirectly by AquiSim Consulting (Pty) Ltd and by the use of the information contained in this document.

COPYRIGHT WARNING

This document is prepared by ARP Consulting, a division of AquiSim Consulting (Pty) Ltd, exclusively for Digby Wells and Associates (South Africa) (Pty) Ltd. It is subject to all confidentiality, copyright, and trade secrets rules, as well as the intellectual property laws and practices of South Africa.

This document contains confidential and proprietary information of AquiSim Consulting (Pty) Ltd. It is protected by copyright equally shared between Digby Wells and Associates (South Africa) (Pty) Ltd and AquiSim Consulting (Pty) Ltd and may not be reproduced or used without the written consent of AquiSim Consulting (Pty) Ltd, which has been obtained beforehand.

Client Information	
Prepared for Environmental Impact Management Services (Pty) Ltd (EIMS)	
Address	8 Dalmeny Road, Pine Park, Randburg, JHB, South Africa
Contact Person	John von Mayer
Contact Email	john@eims.co.za
Contact Number	T. +27 (11) 789 7170

Author Information	
Prepared by ARP Consulting (**A Division of Aquisim Consulting (Pty) Ltd**)	
Address	35 Thys Olivier Street, Dwarswegstrand, GREAT BRAK RIVER, 6525
Contact Person	Dr Japie van Blerk (Director)
Contact Email	japie@aquisim.co.za
Contact Number	+27 (0) 82 806 6159

Document Information and History			
Report Name	Radiological Public Safety Assessment for the Harmony West Wits Reclamation and Deposition Project and Associated Infrastructure		
Report No.	ARP-1008A		
Suggested Citation	ARP Consulting (2026). Radiological Public Safety Assessment for the Harmony West Wits Reclamation and Deposition Project and Associated Infrastructure, Report No. ARP-1008A, Great Brak River, South Africa.		
Project No.	1040-M		
Issue	Version	Date	Revisions
1	0	31.08.2026	

Principal Authors		
		
Name	Dr Japie van Blerk (Director)	Victor Delicado
Qualification	PhD. – Geohydrology	MSc. – Petroleum Geology
SACNASP No.	400239/05	151034
Registration	Radiation Science and Earth Science	Earth Science

Principal Reviewer(s)			
Name			
Qualification			
SACNASP No.			
Registration			

AquiSim Consulting (Pty) Ltd Offices	
109 Bosduif Crescent, Wierda Park x1 P.O. Box 51777, Wierda Park CENTURION 0149 South Africa Cell. No.:+27 (82) 806 6159 e-mail:japie@aquisim.co.za	5 Binga Place, Faerie Glen P.O. Box 1490, Faerie Glen PRETORIA 0043 South Africa Cell. No.:+27 (82) 784-2023 e-mail: Hugo@aquisim.co.za

List of Acronyms

AADQ	Annual authorised discharge quantities
ACR	Authorisation Change Request
ALARA	As Low As Reasonably Achievable
BD	Below Detection
BNG	Breaking New Ground
Bq	Becquerel
CLR	Carbon Leader Reef
CoE	City of Ekurhuleni
CoR	Certificate of Registration
DoE	Department of Energy
DM	District Municipality
DMU	Dustfall Monitoring Units
EIA	Environmental Impact Assessment
ESHIA	Environmental, Social and Health Impact Assessment
FPL	Food Poverty Line
GN	Government Notice
GSR	General Safety Requirement
HDPE	High-density polyethylene
IAEA	International Atomic Energy Agency
ICR	Congress of Radiology
ICRP	International Commission on Radiological Protection
ISAM	Improvement of Safety Assessment Methodologies
LBPL	Lower-bound poverty line
LLα	Long-Lived Radioactive Dust (Alpha)
LM	Local Municipality
LoM	Life of Mine
MAP	Mean Annual Precipitation
MDA	Minimum Detectable Activity
MR	Mining Right
mSv	millisievert
NAAQ	National Ambient Air Quality
NEA	Nuclear Energy Act
Necsa	South African Nuclear Energy Corporation
NEMA	National Environmental Management Act
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act
NORM	Naturally Occurring Radioactive Materials

NRWMP	National Radioactive Waste Management Policy and Strategy
NUREG	US Nuclear Regulatory Commission
NWA	National Water Act
PAEC	Potential Alpha Energy Concentration
PM_{10}	Particulate matter less than 10 microns in size
RDP	Reconstruction and Development Programme
RG	Regulatory Guide
RGM	Radon Gas Monitors
RMP	Radiation Management Programme
RPM	Radiation Protection Monitor
RPO	Radiation Protection Officer
RPP	Radiation Protection Programme
RPS	Radiation Protection Specialist
RPSA	Radiological Public Safety Assessment
RWD	Return Water Dam
SAMPI	South African Multidimensional Poverty Index
SPR	Source-Pathway-Receptor
TSF	Tailings Storage Facilities
TSP	Total Suspended Particles
UBLP	Upper-bound poverty line
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VCR	Ventersdorp Contact Reef
WMA	Water Management Area
WRD	Waste Rock Dump
WW	West Wits

Table of Contents

LIST OF ACRONYMS I

TABLE OF CONTENTS III

LIST OF TABLES VIII

LIST OF FIGURES XII

CREDENTIALS: DR JJ VAN BLERK XVII

CREDENTIALS: MR VE DELICADO XIX

1 INTRODUCTION 1

1.1 Background 1

1.2 Naturally Occurring Radionuclides and Background Radiation 5

1.3 Regulatory Context 6

1.4 Purpose of the Report 7

1.5 Scope and Structure of the Report 7

2 ASSESSMENT CONTEXT 10

2.1 General 10

2.2 Nuclear Regulatory Framework 10

2.2.1 General 10

2.2.2 The ICRP System of Radiological Protection 11

2.2.3 The IAEA Safety Standards 12

2.2.4 International Basic Safety Standards (GSR Part 3) (IAEA, 2014) 13

2.2.5 Safety Standards for the Protection of the Public 13

2.2.6 National Radioactive Waste Management Policy and Strategy 14

2.2.7 Waste Categorisation for Mining and Mineral Processing Facilities 17

2.3 Technical Basis of the Assessment 17

2.3.1 General 17

2.3.2 Interested Parties to the Assessment 18

2.3.3 Purpose and Objectives of the Assessment 18

2.3.4 Scope and Focus of the Assessment 19

2.3.5 Spatial Domain of Concern....22
2.3.6 Assessment Timescales....22
2.3.7 Assessment Endpoint....22
2.4 Assessment Framework and Modelling....26
2.4.1 General....26
2.4.2 Modelling Approach....27
2.5 Assessment Philosophy....28
2.5.1 General....28
2.5.2 Exact Science and Safety Assessments....28
2.5.3 Assessment Approach....29
2.5.4 Management of Uncertainty....30
2.5.5 Public Exposure Conditions....31

3 SYSTEM DESCRIPTION....32
3.1 Introduction....32
3.2 Geographical Setting....32
3.3 Overview of the Kusasalethu Operations....35
3.3.1 General....35
3.3.2 Historical Perspective....35
3.3.3 Mineral Deposit and the Mine Products....36
3.3.4 Mining and Mineral Extraction Process....36
3.4 Surface Infrastructure Relevant to the RPSA....37
3.4.1 General....37
3.4.2 Existing Infrastructure....37
3.4.3 Proposed New Infrastructure....39
3.5 Water Usage and Management....42
3.5.1 Water Use....42
3.5.2 Wastewater and Polluted Water Management....43
3.5.3 Groundwater Management....43
3.6 Description of the Baseline Environment....43
3.6.1 General....43
3.6.2 Regional Topography....46
3.6.3 Hydrology....46
3.6.4 Geology....53

3.6.5 Hydrogeology 55
3.6.6 Groundwater Quality 61
3.6.7 Meteorological Conditions 70
3.7 Socio-Economic Baseline Conditions 76
3.7.1 General 76
3.7.2 Locality and Municipal Context 76
3.7.3 Land Use and Community Types 77
3.7.4 Demographics and Socioeconomic Characteristics 81
3.7.5 Residential Areas and Household Structure 87
3.7.6 Social Infrastructure and Services 89
3.7.7 Human Behavioural Characteristics 97
3.7.8 Summary 104
3.8 Radiological Conditions 107
3.8.1 General 107
3.8.2 Radioactivity Associated with Raw Materials, Products and Residues 107
3.8.3 Environmental Monitoring 111

4 DEFINITION OF PUBLIC EXPOSURE CONDITIONS 122
4.1 Introduction 122
4.2 Key Concepts Used in the SPR Analysis Approach 122
4.3 Source Identification 123
4.3.1 General 123
4.3.2 Primary and Secondary Sources of Radiation Exposure 123
4.3.3 Primary Sources Associated with the Project 124
4.3.4 Secondary Sources Associated with the Project 126
4.3.5 Summary 129
4.4 Pathways 130
4.4.1 General 130
4.4.2 Atmospheric Pathway 130
4.4.3 Groundwater Pathway 139
4.4.4 Surface Water Pathway 140
4.4.5 External Gamma Radiation 142
4.5 Receptors 143
4.6 Timescales 143

4.7 Conceptual Model Development 144
4.7.1 General 144
4.7.2 Conceptual Models for Environmental Pathway Analysis 144
4.7.3 Representation of Conceptual Models for Exposure Conditions 145
4.8 Public Exposure Conditions for the Project 146
4.8.1 General 146
4.8.2 Criteria Used to Define the Discrete Set of Exposure Conditions 147
4.8.3 Definition and Justification of Public Exposure Condition for the Project Area 148

5 CONSEQUENCE ANALYSIS 154
5.1 Introduction 154
5.2 Contribution from Groundwater Pathway 154
5.2.1 General 154
5.2.2 TSF Conceptual Model and Implementation 154
5.2.3 Parameter Values 155
5.2.4 Results 157
5.2.5 Discussion of Results 159
5.3 Dose Contribution from the Atmospheric Pathway 159
5.3.1 General 159
5.3.2 Radionuclide Concentration in Airborne and Deposited Dust 159
5.3.3 Radon Exhalation Rate 160
5.3.4 Radon Inhalation Dose 161
5.3.5 LLα Inhalation Dose 161
5.3.6 External Gamma Radiation 161
5.3.7 Dose Due to Deposition 168
5.4 Total Effective Dose Calculation for Exposure Conditions 168
5.4.1 General 168
5.4.2 Mathematical Equations Used in the Biosphere Analysis 168
5.4.3 Residential Area Exposure Condition 168
5.4.4 Commercial Agricultural Exposure Condition 173

6 SENSITIVITY AND UNCERTAINTY ANALYSIS 178
6.1 General 178
6.2 Aquatic Pathway Analysis 178

6.2.2 Surface Water Pathway 179
6.2.3 Groundwater Pathway 182
6.3 Cumulative Radiological Impact 187
6.4 Variations in Public Exposure Conditions 188
6.4.2 Variation in the Defined Exposure Conditions 188
6.4.3 Alternative Exposure Conditions 188
6.5 Variation in Parameter Values 190
6.5.1 Human Consumption Values 190
6.5.2 Dust Deposition Period 190
6.5.3 Groundwater Pathway Parameters 190

7 IMPACT ASSESSMENT 195
7.1 General 195
7.2 Construction Phase 195
7.3 Operational Phase 195
7.3.1 General 195
7.3.2 Activities 195
7.3.3 Exhalation and Dispersion of Radon Gases 196
7.3.4 Emission and Dispersion of Particulate Matter 197
7.3.5 Retreatment of Existing TSFs 198
7.4 Post-Closure Phase 200
7.4.1 General 200
7.4.2 Activities 200
7.4.3 Implementation of the Decommissioning Plan 201
7.4.4 Exhalation of Radon Gas and Particulate Matter 202
7.4.5 Leaching and Migration of Contaminants from the Project TSF 203
7.5 Cumulative Impact 205

8 RADIATION MONITORING PROGRAMME 207
8.1 General 207
8.2 Baseline Characterisation 207
8.3 Monitoring Programme 207
8.4 Proposed Monitoring Points 208

9 CONCLUSIONS AND RECOMMENDATIONS 209

9.1 General 209

9.2 Conclusions 209

9.3 Recommendations 214

10 REFERENCES 215

APPENDIX A: RADIONUCLIDE AND ELEMENT-DEPENDENT DATA 218

List of Tables

Table 2.1 Summary of the National Radioactive Waste Classification Scheme (DME, 2005). 15

Table 2.2 Management options for low activity NORM and enhanced activity NORM, as defined in DME (2005). 16

Table 2.3 The categorisation of homogeneous process waste and associated management options. 17

Table 2.4 List of α- and β-emitting radionuclides explicitly considered in the Project Radiological Public Safety Assessment. 20

Table 2.5 Age group ranges applicable to age-dependent dose conversion factors as published in RG-002 (NNR, 2013). 21

Table 2.6 Criteria used to determine the impact consequence. 23

Table 2.7 Probability scoring. 24

Table 2.8 Determination of environmental risk. 24

Table 2.9 Significance classes. 24

Table 2.10 The criteria used to determine the prioritisation. 25

Table 2.11 Determination of prioritisation factor 25

Table 2.12 Final environmental significance rating 26

Table 3.1 Summary of existing surface infrastructure and features (see Figure 3.5). 39

Table 3.2 Deelkraal II Design Information (EIMS, 2026). 41

Table 3.3 Kusasalethu Operations surface water discharge points (AquiSim, 2023). 43

Table 3.4 Summary of the surface water use reported for the Kusasalethu Operations (AquiSim, 2023). 49

Table 3.5 Surface water monitoring points at the Kusasalethu Operations (see Figure 3.12 for locations). 52

Table 3.6 Summary of total uranium monitoring measurements (AquiSim, 2023). 52

Table 3.7 Summary of the aquifer parameters obtained from the aquifer test (MvB Consulting, 2026). 57

Table 3.8 Monitoring boreholes in the Project area (MvB Consulting, 2026). 61

Table 3.9 Summary of total uranium monitoring measurements (AquiSim, 2023). 62

Table 3.10 Average monthly rainfall distribution (mm) (Hydrologic Consulting, 2026). 70

Table 3.11 Monthly temperature summary (WRF data, January 2022 to December 2024) (Airshed, 2026). 71

Table 3.12 Site description and location of Kusasalethu Dustfall Monitoring Units (DMU) (Airshed, 2026). 73

Table 3.13 Breakdown of households according to geo-types (source: Census 2011, Census 2022) (Equispectives, 2026). 79

Table 3.14 Change in population, households and population density between 2011 and 2022 (source: Census 2011 and Census 2022) (Equispectives, 2026). 81

Table 3.15 Breakdown of the population distribution in the different areas (source: Census 2022) (Equispectives, 2026). 83

Table 3.16 Gender of the head of household (source: Census 2011) (AquiSim, 2023). 84

Table 3.17 Gender distribution (source: Census 2011) (AquiSim, 2023). 85

Table 3.18 Annual household income (source: Census 2011, shown in percentage) (AquiSim, 2023). 86

Table 3.19 Main dwelling types (households, source: Census 2011) (AquiSim, 2023). 89

Table 3.20 Agricultural activities (households, source: Community Survey 2016) (AquiSim, 2023). 99

Table 3.21 Vulnerability indicators (source: Census 2011, shown in percentage) (AquiSim, 2023). ... 103

Table 3.22 Summary of the socio-economic, demographic and human behavioural data for the area near the Project (AquiSim, 2023; Equispectives, 2026) 105

Table 3.23 Radionuclide Content of Ore Sample (Necsa Report No. RA-03957 dated 10 December 2001). 109

Table 3.24 Full-spectrum radioanalysis results available for the Deelkraal WRD (2008 to 2017). 109

Table 3.25 Full-spectrum radioanalysis results available for the Kusasalethu WRD (2012 to 2022)... 109

Table 3.26 Full-spectrum radioanalysis results available for the Deelkraal TSF (2010 to 2020). 110

Table 3.27 Full-spectrum radioanalysis results available for the Kusasalethu TSF (2010 to 2020). 110

Table 3.28 RGM Measurements taken in the Upcast Vent Shaft at the Kusasalethu Mine (January 2016 to August 2021). 111

Table 3.29 RGM Measurements taken in the Upcast Vent Shaft at the Deelkraal mine (February 2016 to October 2021). 112

Table 3.30 Description of surface water sampling points for full-spectrum analysis performed in 2010 and 2015. 113

Table 3.31 Summary of the full-spectrum analysis (RJ2010-0335, dated 20 September 2010) for 14 surface water sampling points identified for a monitoring campaign in 2010 (see Table 3.30 for description and Figure 3.53 for locations). 113

Table 3.32 Full-spectrum radioanalysis results of surface water samples collected in November 2014 (Necsa Report No. RS2014-0632-01 dated 25 March 2015). 114

Table 3.33 Summary of total uranium concentrations in stream sediments. 114

Table 3.34 Radionuclide activity concentrations in surface water samples collected from the Golf Course sampling point. 117

Table 3.35 Radionuclide activity concentrations in surface water samples collected from the Deelkraal Village Dam sampling point. 118

Table 3.36 Radionuclide activity concentrations in surface water samples collected from the Wedela Stream sampling point. 119

Table 3.37 Summary of full spectrum analysis of three sediment samples from the Welverdiend stream (Necsa Report No. RA-12822 dated 6 June 2012). 120

Table 3.38 Radionuclide activity concentrations in groundwater samples collected in November 2014 (Necsa Report No. RS2014-0632-01 dated 25 March 2015). 120

Table 3.39 Radionuclide activity concentrations in dust filter samples collected in November 2023 (Necsa Report No. RS2023-3298-01 dated 05 February 2024). 121

Table 3.40 Full-spectrum radioanalysis results for fish caught in the Deelkraal Dam in 2000 and 2003 (Botha, 2005). 121

Table 4.1 Summary of surface infrastructure and features of importance to the Project radiological public safety and impact assessment. 125

Table 4.2 Summary of the potential radiological hazards associated with the operational phase of the Project. 129

Table 4.3 Age group-specific indoor and outdoor occupancy factors (NNR, 2013). 149

Table 5.1 Summary of the activity concentrations relevant to the Deelkraal II TSF. 156

Table 5.2 Summary of facility-specific parameter values necessary to calculate the leaching of radionuclides from the Deelkraal II TSF. 156

Table 5.3 Distribution coefficients from literature for the elements of concern, as well as the K_d values in the analysis for illustrative purposes (NNR, 2013; Yu *et al.*, 1993). 157

Table 5.4 Aquifer parameters assumed for the TSFs and areas of concern to calculate the advective flow and migration of radionuclides. 157

Table 5.5 Summary of the nuclide-specific activity concentrations of tailings and waste rock samples available for the Kusasalethu Operations (AquiSim, 2023). 160

Table 5.6 Estimated average and maximum radon exhalation rates for the surface facilities listed in Table 5.5 associated with the Project area. 161

Table 5.7 Route-specific contribution to the total effective dose at receptor locations identified for the Residential Area Exposure Condition (see Figure 5.11). 172

Table 5.8 Route-specific contribution to the total effective dose at receptor locations identified for the Commercial Agricultural Exposure Condition (see Figure 5.13). 177

Table 6.1 Summary of the surface water activity concentrations that are considered in the uncertainty analysis, as derived from the data presented in AquiSim (2023). 179

Table 6.2 Total effective dose induced using water for the Golf Course monitoring point for household and subsistence farming purposes. 180

Table 6.3 Total effective dose induced using water for the Deelkraal Village Dam monitoring point for household and subsistence farming purposes. 180

Table 6.4 Total effective dose induced using water for the Wedela monitoring point for household and subsistence farming purposes. 181

Table 6.5 Summary of the average radiological monitoring data for groundwater samples collected in the vicinity of the Project from AquiSim (2023). 183

Table 6.6 Total effective dose induced using water from MBH14 for household and subsistence farming purposes. 184

Table 6.7 Total effective dose induced using water from MBH15 for household and subsistence farming purposes. 184

Table 6.8 Total effective dose induced using water from MBH16 for household and subsistence farming purposes. 185

Table 6.9 Total effective dose induced using water from MBH17 for household and subsistence farming purposes. 185

Table 7.1 Summary of the activities and the impact of the activities during the operational phase of the Project. 196

Table 7.2 Impact significance rating for the exhalation and dispersion of radon gas during the operational phase of the Project. 197

Table 7.3 Impact significance rating for the particulate matter emission and dispersion that contains radionuclides during the operational phase of the Project. 199

Table 7.4 Impact significance rating for the retreatment of the existing TSFs during the operational phase of the Project. 200

Table 7.5 Summary of the activities and the impact of the activities during the post-closure phase. 201

Table 7.6 Impact significance rating for the implementation of the decommissioning plan of the Project. 202

Table 7.7 Impact significance rating for the exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of the Project. 204

Table 7.8 Impact significance rating for the leaching and migration of radionuclides from the TSFs during the post-closure phase of the Project. 205

Table 8.1 Summary of the environmental monitoring programme proposed for the Project aimed at public radiation protection. 208

Table 9.1 Summary of the radiological impact significance rating for the operational phase of the Project. 210

Table 9.2 Summary of the radiological impact significance rating for the post-closure phase of the Project. 212

List of Figures

Figure 1.1 Map showing the location of the four discrete Harmony operations in South Africa. The focus of this report is the Kusasaletu Operations of Harmony (AquiSim, 2023). 2

Figure 1.2 Regional locality map showing the Kusasaletu Operations of Harmony in the Merafong City Local Municipality within the Southern District Municipality of the Northwest Province of South Africa (AquiSim, 2023). 3

Figure 1.3 Local locality map showing the surface infrastructure associated with the Kusasaletu Operations relative to local communities and neighbouring mines (AquiSim, 2023). 4

Figure 1.4 Distribution of the background radiation contribution as a percentage of the annual dose, averaged over the population of the world [Reproduced from IAEA (2004a)]. 5

Figure 1.5 Schematic illustration of the conceptual assessment framework used to perform the radiological public safety assessment of the Project. 8

Figure 2.1 Hierarchy of the IAEA safety standards consisting of safety fundamentals, safety requirements and safety guides. 12

Figure 2.2 The long-term structure of the IAEA Safety Standards (IAEA, 2011). 12

Figure 3.1 Regional locality map showing the Project of Harmony in the Merafong City Local Municipality within the Southern District Municipality of the Northwest Province of South Africa (EIMS, 2026). 33

Figure 3.2 Location of the Kusasalethu Operations relative to surrounding communities (AquiSim, 2023). 34

Figure 3.3 Schematic diagram of the Kusasalethu Operations shaft and mining layout (AquiSim, 2023). 35

Figure 3.4 Basic mining and metallurgical processes utilised at gold mining and mineral processing operations (AquiSim, 2023). 36

Figure 3.5 Map showing the existing surface infrastructure and features that are of importance (AquiSim, 2023). 38

Figure 3.6 Deelkraal II TSF compartments (EIMS, 2026). 41

Figure 3.7 Comparison of typical Class C liner and inverted liner system (EIMS, 2026). 42

Figure 3.8 Deelkraal TSF monitoring borehole (MvB Consulting, 2026). 44

Figure 3.9 Kusasalethu Boreholes (MvB Consulting, 2026). 45

Figure 3.10 Regional topography and drainage of the Project area (MvB Consulting, 2026). 47

Figure 3.11 Surface water drainage in the Project Area (AquiSim, 2023). 50

Figure 3.12 Surface and groundwater monitoring points at the Kusasalethu Operations (AquiSim, 2023). 51

Figure 3.13 Regional geology shows that the Project falls in the Far West Rand Goldfield (West Wits Line), on the north-western rim of the geologically unique Witwatersrand Basin (AquiSim, 2023). 54

Figure 3.14 Surface geology underlying the Project (MvB Consulting, 2026). 56

Figure 3.15 Relationship between the groundwater level elevation and the corresponding topography (MvB Consulting, 2026). 58

Figure 3.16 Conceptual hydrogeological model for the Project Area (MvB Consulting, 2026). 59

Figure 3.17 The groundwater levels and flow directions as determined by MvB Consulting (2026). 60

Figure 3.18 Hydrocensus borehole locality – Kusasalethu area (MvB Consulting, 2026). 63

Figure 3.19 Hydrocensus borehole locality – Deelkraal area (MvB Consulting, 2026). 64

Figure 3.20 Current SO_4 plume at the Deelkraal mine (MvB Consulting, 2026). 66

Figure 3.21 Current SO_4 plume at the Kusasalethu mine (MvB Consulting, 2026). 67

Figure 3.22 The simulated mitigated SO_4 plume after 50 years at the Deelkraal mine (MvB Consulting, 2026). 68

Figure 3.23 The simulated SO_4 plume after 50 years at the Kusasalethu mine (MvB Consulting, 2026). 69

Figure 3.24 Diurnal monthly temperature trends (WRF data, January 2022 to December 2024) (Airshed, 2026). 71

Figure 3.25 Period, day and night-time wind roses (WRF data, January 2022 to December 2024) (Airshed, 2026). 72

Figure 3.26 Seasonal wind roses (WRF data, January 2022 to December 2024) (Airshed, 2026). 72

Figure 3.27 Daily PM_{10} concentrations measured at the Kusasalethu Operations from mid-December 2014 to mid-March 2015 (AquiSim, 2023). 73

Figure 3.28 Dustfall rates from January 2020 to December 2020 for Residential sites (Airshed, 2022). . 74

Figure 3.29 Measured dustfall at the project site for the period January 2020 to September 2021 (Airshed, 2026). 74

Figure 3.30 Kusasalethu Dustfall Monitoring Units (DMU) (Airshed, 2026). 75

Figure 3.31 Regional locality map showing the location of the Project (Equispectives, 2026). 80

Figure 3.32 Map indicating the study area used for the Project Baseline Social and Land Use Assessment (AquiSim, 2023). 82

Figure 3.33 Household size (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 83

Figure 3.34 Age distribution of the population (shown in percentage; source: Census 2011, Census 2022) (Equispectives, 2026). 84

Figure 3.35 Labour status (those aged between 15 - 65 years, shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 86

Figure 3.36 Dwelling types (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 88

Figure 3.37 Houses in the Elandsrand residential area (AquiSim, 2023). 90

Figure 3.38 Houses in Deelkraal estate (AquiSim, 2023). 90

Figure 3.39 Wedela as viewed from the Kusasalethu TSF (AquiSim, 2023). 91

Figure 3.40 Housing structures in agricultural areas (AquiSim, 2023). 91

Figure 3.41 Supermarket in Deelkraal Estate (AquiSim, 2023). 93

Figure 3.42 Recreational facilities at Deelkraal Dam (AquiSim, 2023). 93

Figure 3.43 Water Source (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 94

Figure 3.44 Piped water (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 95

Figure 3.45 Refuse removal (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 96

Figure 3.46 Energy source for lighting (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 96

Figure 3.47 Sanitation (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026). 97

Figure 3.48 Vegetable garden of a nursery school in Elandsrand (AquiSim, 2023). 100

Figure 3.49 Vegetable gardens in Deelkraal Estate (AquiSim, 2023). 101

Figure 3.50 Vegetable garden on a Deelkraal farm (AquiSim, 2023). 101

Figure 3.51 Examples of livestock farming on the Deelkraal farms (AquiSim, 2023). 102

Figure 3.52 Locality map showing the most vulnerable community near the Project (AquiSim, 2023). 108

Figure 3.53 Map showing the location of surface water and groundwater monitoring points available to determine the potential influence of the aquatic pathway on the total annual effective dose (see Table 3.8 and Table 3.30 for description). 115

Figure 3.54 Sediment samples from the Welverdiend stream measuring below and above 50 mg.kg^{-1} uranium. 116

Figure 4.1 The simulated current annual average airborne PM_{10} concentrations (in units of µg.m^{-3}) attributed to the Kusasalethu Operations. 131

Figure 4.2 The simulated future annual average airborne PM_{10} concentrations (in units of µg.m^{-3}) attributed to the Project. 132

Figure 4.3 The simulated current annual average airborne TSP deposition rate (in units of mg.m^{-2}.day^{-1}) attributed to the Kusasalethu Operations. 134

Figure 4.4 The simulated future annual average airborne TSP deposition rate (in units of mg.m^{-2}.day^{-1}) attributed to the Project. 135

Figure 4.5 The simulated current annual average radon concentration for the Kusasalethu Operations, as derived from data from Airshed (2026). 136

Figure 4.6 The simulated future annual average radon concentration for the Project, as derived from data from Airshed (2026). 137

Figure 4.7 Features, processes, and associated exposure modes to consider when calculating the atmospheric pathway's contribution to the total dose. 138

Figure 4.8 Processes affecting the movement of radionuclides from the point of discharge into a surface water body (IAEA, 2001). 140

Figure 4.9 Features, processes, and associated exposure modes to consider when calculating the groundwater pathway's contribution to the total dose. 141

Figure 4.10 Features, processes, and associated exposure modes to consider when calculating the surface-water pathway's contribution to the total dose. 142

Figure 4.11 The model development process in relation to other elements of the assessment framework presented in Figure 1.5. 145

Figure 4.12 A simple 2x2 Interaction Matrix, showing the interaction between features, events and processes in a safety assessment. 146

Figure 4.13 Principle of a radionuclide migration path through the Interaction Matrix. 146

Figure 4.14 A flow diagram is a conceptual model for a specific exposure condition, illustrating the exposure pathways and the relationships among the system's compartments. 147

Figure 4.15 Conceptual flow diagram of the exposure pathways associated with a Residential Area Exposure Condition. 150

Figure 4.16 Conceptual Interaction Matrix of the exposure pathways associated with Residential Area Exposure Condition. 150

Figure 4.17 Conceptual flow diagram of the exposure pathways associated with the Commercial Agricultural Exposure Condition. 152

Figure 4.18 Conceptual Interaction Matrix of the exposure pathways associated with the Commercial Farming Exposure Condition. 153

Figure 5.1 Conceptual representation of the model compartment included in the System Level modelling of the groundwater pathway (Not to Scale). 155

Figure 5.2 Screen capture of the model implementation in AFRY ISM used to evaluate the contribution of the groundwater pathway for the Project. 155

Figure 5.3 The simulated activity concentration in groundwater abstracted from a borehole 500 m from the Deelkraal II TSF. 158

Figure 5.4 The simulated water ingestion dose to the different age groups 500 m from the Deelkraal II TSF, using the activity concentrations in Figure 5.3. 158

Figure 5.5 The distribution of the adult radon inhalation dose induced by the current facilities associated with the Kusasalethu Operations, based on the airborne radon concentration presented in Figure 4.5. 162

Figure 5.6 The distribution of the adult radon inhalation dose induced by the future facilities associated with the Project, based on the airborne radon concentration presented in Figure 4.6. 163

Figure 5.7 The simulated current annual average adult airborne dust inhalation dose (in units of $\mu Sv.year^{-1}$) as derived from PM_{10} data presented in Section 4.4.2. 164

Figure 5.8 The simulated future annual average adult airborne dust inhalation dose (in units of μSv.year^{-1}) as derived from PM_{10} data presented in Section 4.4.2. 165

Figure 5.9 The current annual average adult external gamma radiation dose (in units of μSv.year^{-1}) as a contribution from groundshine, as derived from TSP data presented in Section 4.4.2 166

Figure 5.10 The future annual average adult external gamma radiation dose (in units of μSv.year^{-1}) as a contribution from groundshine, as derived from TSP data presented in Section 4.4.2 167

Figure 5.11 Dose isopleths for the 0 to 2 years age group depicting the contribution of the Project to a Residential Area Exposure Condition. 170

Figure 5.12 Total effective doses to different age groups at receptor locations identified for the Residential Area Exposure Condition (see Figure 5.11 for locations). 171

Figure 5.13 Dose isopleths for the adult age group depicting the contribution of the Project to a Commercial Agricultural Exposure Condition. 175

Figure 5.14 Total effective doses to different age groups at receptor locations identified for the Commercial Agricultural Exposure Condition (see Figure 5.13 for locations). 176

Figure 6.1 Summary of the total effective doses calculated for the different age groups for the data presented in Table 6.2 to Table 6.4. 181

Figure 6.2 Graph showing the increase in total effective dose to the different age groups due to continuous irrigation with water with radiological properties listed in Table 6.1. 182

Figure 6.3 Summary of the total effective doses calculated for the different age groups for the data presented in Table 6.6 to Table 6.9 as their only source of water to sustain a subsistence farm. 186

Figure 6.4 Graph showing the increase in total effective dose to the different age groups due to continuous irrigation with water with radiological properties listed in Table 6.5. 187

Figure 6.5 Total effective dose for the Deelkraal II TSF as a function of the exposure period. 189

Figure 6.6 The simulated water ingestion dose for the 0 to 2 years age group using different source durations for the Deelkraal II TSF. 191

Figure 6.7 The simulated water ingestion dose to the 0 to 2 years age group using different Kd-values for the Deelkraal II TSF and underlying hydrogeology. 192

Figure 6.8 The simulated water ingestion dose to the 0 to 2 years age group using different hydraulic conductivity (K) values for the underlying hydrogeology. 192

Figure 6.9 The simulated water ingestion dose to the 0 to 2 years age group using different distances from the Deelkraal II TSF to an abstraction borehole. 193

Figure 6.10 The simulated water ingestion dose to the 0 to 2 years age group using different aquifer depths underneath the Deelkraal II TSF. 193

Figure 6.11 The simulated water ingestion dose to the 0 to 2 years age group using different unsaturated zone thicknesses below the Deelkraal II TSF. 194

Credentials: Dr JJ van Blerk



Dr Japie van Blerk is the Director of AquiSim Consulting (Pty) Ltd (AquiSim), a position he has held for 21 years. Previously, he worked at the South African Nuclear Energy Corporation (Necsa) for 11 years, where he was primarily responsible for the post-closure safety assessment of the Vaalputs National Radioactive Waste Disposal Facility. During his tenure at Necsa, Dr. van Blerk earned a PhD in geohydrology from the University of the Free State in South Africa. He is a registered Professional Natural Scientist (Pr.Sci.Nat.) in the fields of Radiation Science and Earth Science (Reg. no 400239/05) through the South African Council for Natural Scientific Professions (SACNASP).

Dr. van Blerk gained extensive expertise in the performance of near-surface radioactive waste disposal systems, particularly under arid conditions, through his role in the post-closure safety assessment of the Vaalputs National Radioactive Waste Disposal Facility. After joining AquiSim Consulting (Pty) Ltd (AquiSim) in 2000, he continued to provide consulting services to the South African Nuclear Energy Corporation (Necsa), focusing on radioactive waste management and post-closure safety assessments. Notably, Dr. van Blerk collaborated with Dr Matt Kozak from Interra, USA, to prepare the current Vaalputs post-closure safety assessment. This assessment involved an in-depth review of the national inventory of radioactive waste designated for disposal at Vaalputs.

Dr. van Blerk further expanded his experience and knowledge of radioactive waste disposal in arid conditions through a collaborative project with Facilia AB (Sweden). This project involved evaluating the post-closure safety of a borehole-type facility for Disused Sealed Radioactive Sources (DSRS) at Sandy Ridge, Western Australia, with Tellus Holding Ltd as the primary client.

Over the past 23 years, Dr. van Blerk has provided extensive consultancy and technical training services to the International Atomic Energy Agency (IAEA). His work with the IAEA has encompassed a wide range of fields, including post-closure safety assessment, safety case development, radioactive waste management (including Naturally Occurring Radioactive Material or NORM), the development of disposal concepts for Deep Seabed Radioactive Waste (DSRS), and the cradle-to-grave management of DSRS.

Dr. van Blerk, through his extensive involvement in IAEA-related projects, has developed deep knowledge and experience in applying IAEA safety standards for radioactive waste disposal and management. His expertise spans all stages of the radioactive waste management cycle, including site selection, site characterisation, disposal concept design, disposal, final closure, and the application of post-closure safety assessments to inform decision-making at each stage.

In addition to his work in the nuclear sector, Dr. van Blerk has substantial experience conducting and managing radiological public safety assessments for mining and mineral processing facilities, particularly those involving Naturally Occurring Radioactive Material (NORM). His work has been conducted both locally and internationally, covering a wide range of operations, including uranium, gold, rare earth, copper, mineral sands, and phosphate, among others. These assessments have been conducted for regulatory, environmental, and Social Impact Assessment (ESIA) purposes under both operational and post-operational conditions.

Over the past 21 years, Dr. van Blerk has managed and performed more than 70 radiological public safety assessment projects for the NORM and nuclear industries. While many of these projects were based in South Africa, his work has also extended to Namibia, Mozambique, Madagascar, Ukraine, Kazakhstan, Mali, and Malawi.

Complementing his expertise in the nuclear industry, Dr van Blerk possesses a strong working knowledge of various environmental processes and disciplines, including geology, geohydrology, geochemistry, hydrology, and meteorology. His understanding of these disciplines, combined with his knowledge of groundwater modelling principles for both saturated and unsaturated conditions, makes him well-suited to review waste disposal programs and assess their impacts on human health and the environment during the post-closure period.

Certification

I, the undersigned, certify that to the best of my knowledge and belief, the above information is an accurate description of my experience and qualifications.



Jacobus Josia van Blerk (PhD)

Director: AquiSim Consulting (Pty) Ltd

Credentials: Mr VE Delicado



Mr Victor Delicado is a consulting hydrogeologist with 9 years of experience completing high-level, complex hydrogeological projects for mining clients. Before this, he earned an MSc in Petroleum Geology from the University of the Western Cape in South Africa. He is a registered Professional Natural Scientist (Pr.Sci.Nat.) in the field of Earth Science (Reg. no. 151034) with the South African Council for Natural Scientific Professions (SACNASP).

Mr Delicado gained extensive expertise in geological permeability testing (packer testing), geochemical and hydrochemical analyses, and dewatering modelling, ultimately informing and aiding decision-making (Capex and Opex cost modelling) for site-specific dewatering strategies.

During this period, he provided consultancy services to several high-profile local and international clients, including Tharisa Minerals, Glencore Chrome, Anglo Platinum, and Lucara Diamond Corp. His work spanned multiple commodities, including gold, PGMs, and diamonds, across countries such as South Africa, Mozambique, Botswana, Malawi, Zimbabwe, Australia, and Finland. Further to this, Mr Delicado expanded his experience and knowledge in radioactive waste disposal in arid conditions through a collaborative project for Aramco in Saudi Arabia. This project involved constructing a process-level hydrogeological numerical model to evaluate the potential post-closure movement of Naturally Occurring Radioactive Material (NORM) waste in deep aquifer systems via deep-well injection. In addition to his work in the mining and minerals sector, Mr Delicado has recently begun gaining experience in performing radiological public safety assessment projects for mining and mineral processing facilities, particularly those involving Naturally Occurring Radioactive Material (NORM). His work has covered a range of operations, including uranium and gold. These assessments have been conducted for regulatory, environmental, and Environmental and Social Impact Assessment (ESIA) purposes under both operational and post-operational conditions.

Complementing his expertise, Mr Delicado possesses a strong working knowledge of various environmental processes and disciplines, including geology, geohydrology, geochemistry, and hydrology. His understanding of these disciplines, combined with his knowledge of groundwater modelling principles for both saturated and unsaturated conditions, makes him well-suited to conduct waste-disposal studies and assess their impact on human health and the environment during the post-closure period.

Certification

I, the undersigned, certify that to the best of my knowledge and belief, the above information is an accurate description of my experience and qualifications.



Mr Victor Edward Delicado (MSc)

AquiSim Radiological Protection (ARP) Consulting

1 Introduction

1.1 Background

Harmony Gold Mining Company Limited (Harmony) has an internationally diversified portfolio of gold mining projects in South Africa, with a growing international footprint in copper and gold in Papua New Guinea and Australia.

The company has nine underground mines, one open-pit mine, and several surface tailings-retreatment operations in South Africa. In Papua New Guinea, Harmony has several interests, including one copper-gold block-cave project, namely the Wafi-Golpu project, and one open-pit gold and silver mining operation, the Hidden Valley project. Harmony also has extensive exploration tenements. In Australia, they have interests in the CSA underground copper mine and the Eva Copper Project, an iron-oxide-copper-gold resource, as well as 16 exploration tenements.

Figure 1.1 shows that Harmony's South African interests are divided into four discrete operations: the Free State Operations, the West Rand Operations, the Klerksdorp goldfields, and the Kraaipan Greenstone Belt (Kalgold Operations). Through these various operations, Harmony has made significant economic contributions to the provinces where it operates by creating jobs and stimulating secondary services and industries (AquiSim, 2023).

The Kusasaletu Operations of Harmony form part of the West Rand Operations and comprise the former Elandsrand and Deelkraal mines, located adjacent to Harmony's operational Mponeng and Savuka mining lease areas. Figure 1.2 shows that the Kusasaletu Operations are situated near the towns of Carletonville, Fochville, and Wedela in the magisterial area of Merafong City Local Municipality, within the Southern District Municipality of the Northwest Province of South Africa.

The Kusasaletu Operations consist mainly of underground workings and, on the surface, include a gold processing plant, tailings storage facilities (TSFs), waste rock dumps (WRDs), a backfill plant, and two upcast ventilation shafts. The gold processing plant at the former Deelkraal mine has been decommissioned and partially demolished. Figure 1.3 presents a locality map showing the surface infrastructure associated with the Kusasaletu Operations in relation to local communities, the neighbouring mines and associated infrastructure (AquiSim, 2023).

Randfontein Estates Limited (a subsidiary of Harmony Gold Mining Company) is in the process of lodging an application for the development of the proposed new Deelkraal II TSF project and associated infrastructure (EIMS, 2026).

The proposed Harmony West Wits Reclamation and Deposition Project (hereinafter referred to as the Project) was developed to address Harmony's need for additional deposition capacity for the West Rand Operations. Harmony plans to construct the Deelkraal II TSF to accommodate additional future capacity. This TSF will receive residue from the Kusasalethu and Savuka plants and will also assist in returning process water to reclaim the existing Deelkraal 1 TSF and the Kusasalethu TSF for processing at the Kusasalethu plant. Additional planned infrastructure includes slurry, potable, sewage, and return-water pipelines; access roads; pump stations; a return-water dam; and a power line. Upgrades to the existing Kusasalethu plant are also proposed as part of the project.

The Deelkraal II TSF is located approximately 13 km southwest of Carletonville in the Merafong City Local Municipality, West Rand District Municipality, Gauteng Province.

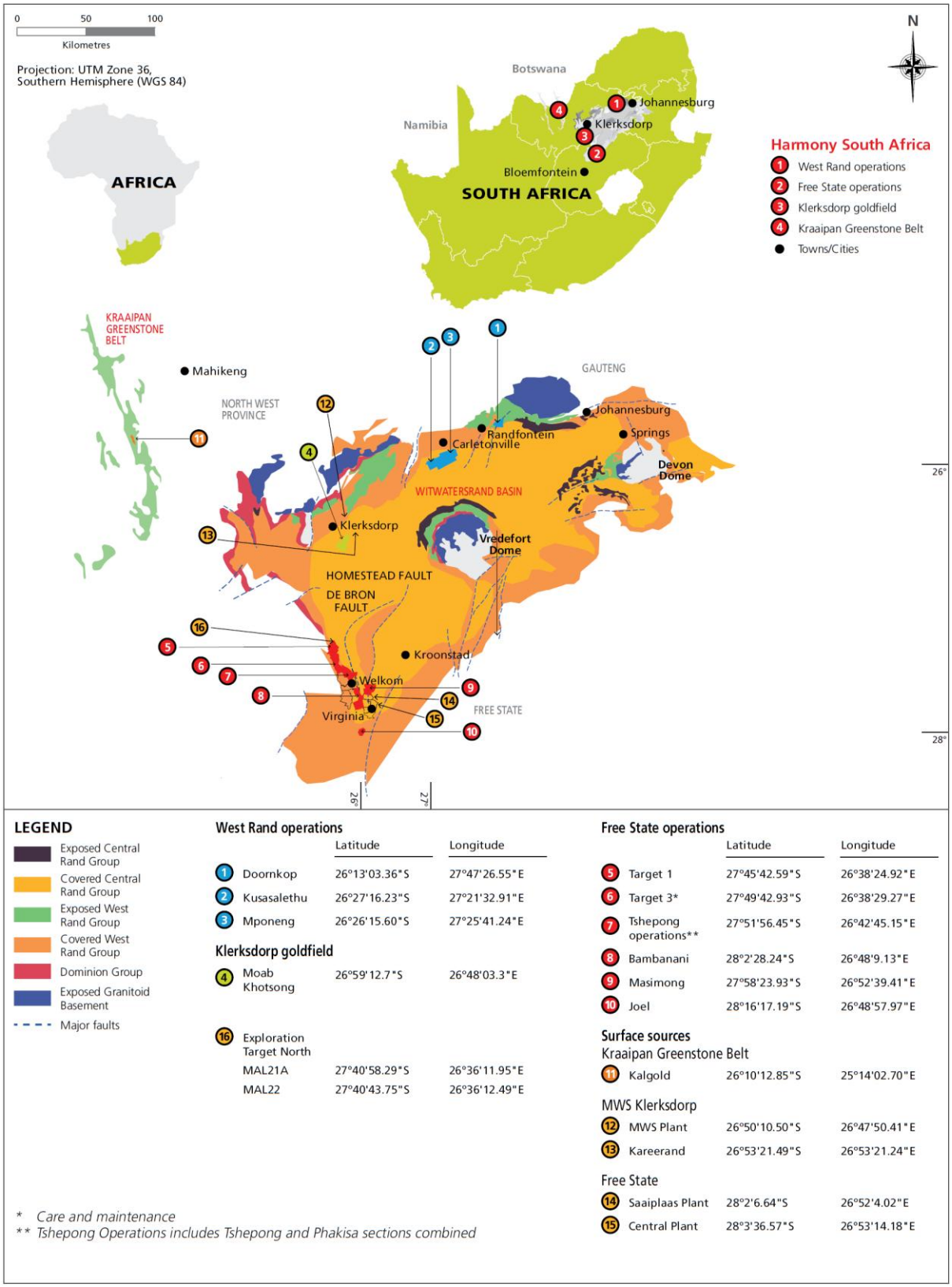


Figure 1.1 **Map showing the location of the four discrete Harmony operations in South Africa. The focus of this report is the Kusasaletu Operations of Harmony (AquiSim, 2023).**

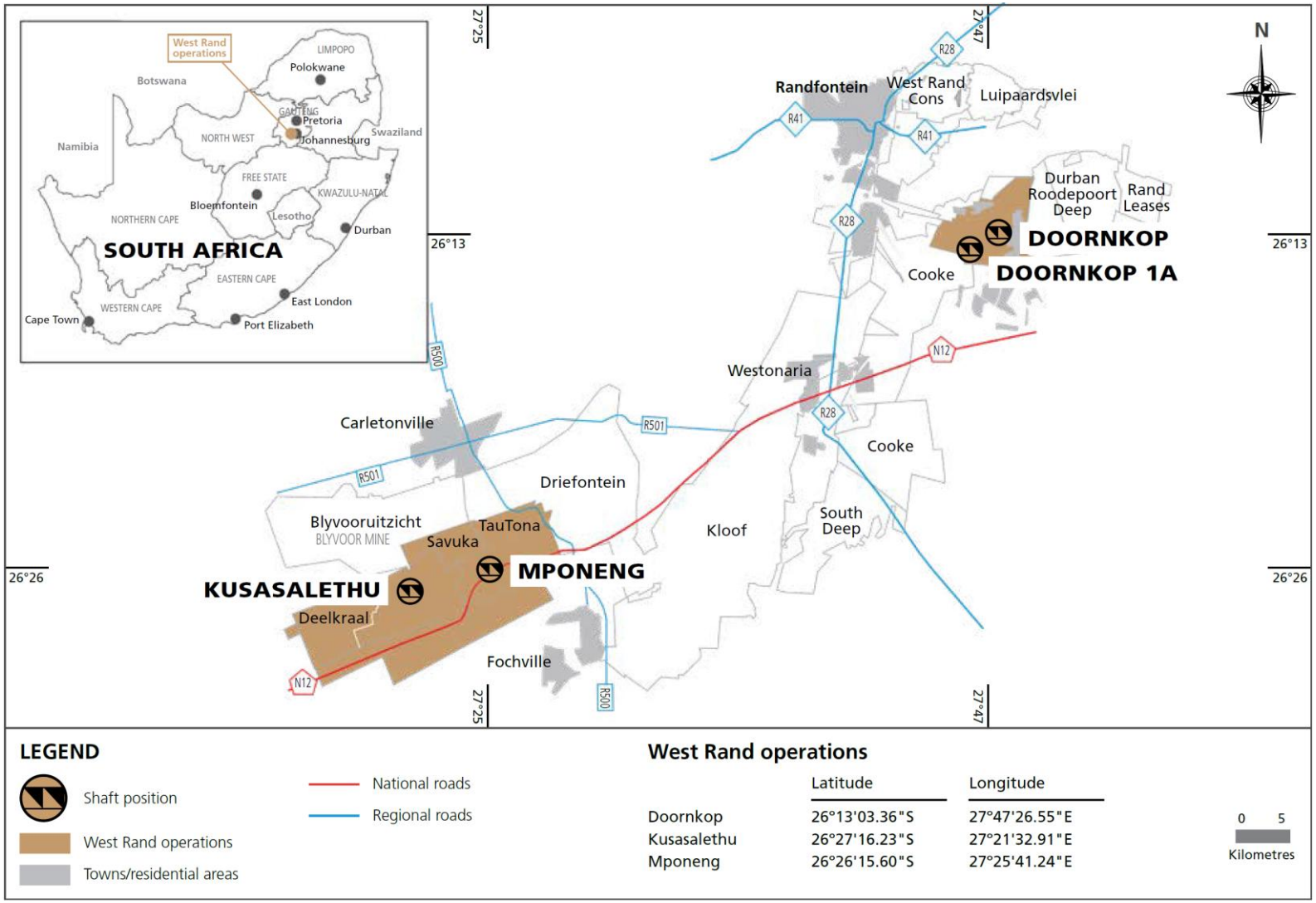


Figure 1.2 **Regional locality map showing the Kusasaletu Operations of Harmony in the Merafong City Local Municipality within the Southern District Municipality of the Northwest Province of South Africa (AquiSim, 2023).**



Figure 1.3 **Local locality map showing the surface infrastructure associated with the Kusasaletu Operations relative to local communities and neighbouring mines (AquiSim, 2023).**

1.2 Naturally Occurring Radionuclides and Background Radiation

Many radioactive isotopes (or radionuclides) occur naturally throughout the Earth's crust and are present in most rocks, soils, river water, and seawater. Most of these naturally occurring radionuclides are members of four radioactive series, identified as the uranium (U-238), actinium (U-235), thorium (Th-232), and neptunium (Np-237) series, named after the radionuclides that serve as progenitors (or parents) of the series products. Naturally occurring radionuclides that are of particular interest to radiation protection, which are not members of any of the four decay series, include isotopes of potassium (K-40) and rubidium (Rb-87). These isotopes are of interest because they are present in environmental media and contribute to human exposure (Martin, 2006a).

In undisturbed environmental conditions, the naturally occurring radionuclides form part of the natural background radiation to which all humans are exposed daily through the air they breathe, the water they drink, the soil they live and work on, and the food they eat (Kathren, 1998).

The annual dose, averaged across the global population, is approximately 2.8 mSv. As indicated in Figure 1.4, over 85% of this total is from natural sources, with about half coming from radon decay products in the home (2.4 mSv). Medical exposure to patients accounts for 14% of the total (0.4 mSv), whereas all other artificial sources — fallout, consumer products, occupational exposure, and discharges from the nuclear industry — account for less than 1% of the total. Other natural background radiation sources include cosmic radiation, gamma radiation, and internal radiation in our bodies (IAEA, 2004a).

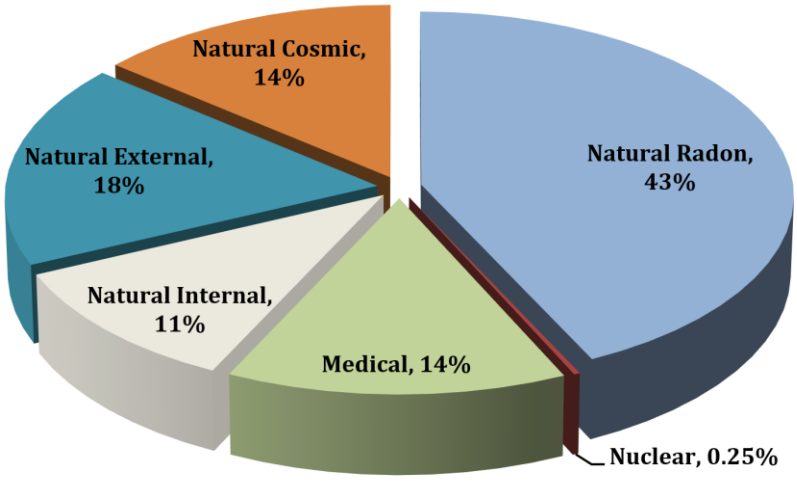


Figure 1.4 Distribution of the background radiation contribution as a percentage of the annual dose, averaged over the population of the world [Reproduced from IAEA (2004a)].

In addition to natural background radiation, anthropogenic activities that exploit Earth's resources may increase the potential for human exposure to naturally occurring radionuclides through their products, by-products, residues, and other wastes. Industries such as mining, mineral processing and related activities have the potential to alter the natural background radiation and potentially increase radiation exposure by:

- Moving naturally occurring radionuclides from inaccessible locations to places where humans can be exposed;
- Concentrating radionuclides in environments accessible to humans; and
- Changing the chemical or physical environment in ways that make previously immobile radionuclides more mobile, such as increasing their solubility in water or their transportability by wind.

Naturally occurring radionuclides associated with the uranium, thorium and actinium decay series are associated in varying degrees with the gold-bearing reefs of the Witwatersrand Basin. These naturally occurring radionuclides are present in ore brought to the surface for processing. They are consequently carried through to the mineral processing residues, which are now stored on the surface as tailings or waste rock facilities.

According to the International Atomic Energy Agency (IAEA) Safety Glossary (IAEA, 2018), materials handled, processed, or produced during mining and mineral processing that contain naturally occurring radionuclides are classified as Naturally Occurring Radioactive Material (NORM). The presence of these radionuclides in NORM can pose potential health risks to humans exposed to these materials, as emphasised by Marsh *et al.* (2010).

Nationally and internationally, the contribution of natural background radiation is not subject to regulatory control. Therefore, the focus of assessments like the one for the Project is on the contribution of the operations to public ionising radiation exposure conditions beyond natural background levels, known as complementary exposure. The main approach followed for this purpose involves measuring, calculating, or estimating the release rate of radioactivity from sources associated with the operations, determining how this radioactivity disperses into the environment, and analysing the subsequent interaction of the public with the affected environmental media. This approach is particularly suitable for new or proposed operations that have no history of environmental releases.

When necessary and justified, this approach is complemented by direct environmental measurements, such as sampling soil, water, sediment, crops, and other relevant media. These measurements help quantify the contribution to the annual effective dose received by members of the public. However, it is important to note that these environmental measurements likely include contributions from natural background radiation, making it essential to distinguish between background and operation-related radiation exposure.

1.3 Regulatory Context

In South Africa, the protection of human health and the environment from adverse effects associated with exposure to ionising radiation is regulated in terms of the National Nuclear Regulator Act (NNRA) (Act 47 of 1999) as amended in the National Nuclear Regulator Amendment Act (NNRAA) (Act 26 of 2024), and the Nuclear Energy Act (NEA) (Act No. 46 of 1999). The NNRA established the National Nuclear Regulator (NNR) as the statutory body responsible for regulating the nuclear industry and NORM associated with mining and mineral processing. The legal limit for material to be classified as *radioactive* in terms of national standards (published in terms of the NNRA) is 0.5 $Bq.g^{-1}$ or 500 $Bq.kg^{-1}$ (radionuclide specific).

Section 22(1) of the NNRA states:

> "*Any person wishing to engage in any activity, not contemplated in Section 21(1), (2), (3) or (4), must apply in the prescribed form and manner to the chief executive officer for a certificate of registration, certificate of exemption, authorisation to design or authorisation to manufacture and must furnish such information as the board requires*".

Harmony holds a Certificate of Registration (CoR-28) granted by the NNR under Section 22 of the NNRA for the Kusasalethu Operations. One of the key submissions as part of an Authorisation Change Request (ACR) to the NNR is a Radiological Public Safety Assessment (RPSA), which assesses the potential radiological impact and safety of the proposed changes or listed activities on members of the public.

The current radiological public safety assessment for the Kusasalethu Operations was performed and submitted to the NNR in 2022 (AquiSim, 2023). Due to the proposed changes associated with the Project, a revised and updated RPSA is required. The revision considers the potential additional radiological impact that the construction of the Deelkraal II TSF would pose. Where necessary and justified, reference is made to the 2022 Kusasalethu Operations RPSA.

AquiSim Consulting (Pty) Ltd (AquiSim) was consequently commissioned as a Radiation Protection Specialist (RPS) to perform the RPSA for the Project in a manner that is consistent with the provisions, requirements, and guidelines provided by the NNR.

1.4 Purpose of the Report

Due to the presence of naturally occurring radionuclides in the tailings material that will be reclaimed and deposited by the Project, Harmony is legally obligated to assess the potential radiological safety of the Project as part of the broader Environmental, Social and Health Impact Assessment (ESHIA) process.

The purposes of the RPSA within the broader ESHIA and as part of the overall Radiation Management Programme (RMP) are, amongst others, to demonstrate to the NNR and other stakeholders that the potential radiological impact induced by the Project is within the compliance criteria set to protect members of the public from exposure to ionising radiation. The output and findings of the RPSA are therefore well suited to communicate the potential radiological impact on members of the public as part of an ESHIA process.

From this perspective, the purpose of this report is to present the current RPSA of the Project in alignment with the NNRA, the NEA, and the relevant requirements, guidance, and regulations set forth by the NNR.

1.5 Scope and Structure of the Report

The report assumes that readers have a basic understanding of ionising radiation and its effects on human health and the environment. For those seeking additional information on these subjects, reference can be made to readily available literature, such as *Radiation, People and the Environment,* published by the IAEA (IAEA, 2004a) or "*Radiation Effects and Sources*", published by the United Nations Environmental Programme (UNEP, 2016).

Various approaches can be used to conduct an RPSA, and no single method is considered definitive or correct. What matters is that the chosen approach is fit for purpose, instils confidence in the assessment results, and takes into account the principles of a graded approach to safety assessment (IAEA, 2009a).

Figure 1.5 illustrates schematically the conceptual framework used to perform the RPSA of the Project. It resembles the IAEA ISAM (Improvement of Safety Assessment Methodologies) methodology developed for the safety assessment of near-surface radioactive waste disposal facilities (IAEA, 2004b). It is inherently systematic and structured, allowing for the continual improvement of the assessment or its components through successive iterations. The assessment framework comprises several interrelated elements, presented in different sections of this report. The overall report structure is as follows:

- Section 2 presents an overview of the assessment context, which defines the high-level assumptions and constraints imposed on the assessment.
- Section 3 provides a more detailed description of the Project, including the regional and local setting and the associated operational components. An overview of the physical environment and the human receptors potentially affected by the Project is also presented to complete the system description.

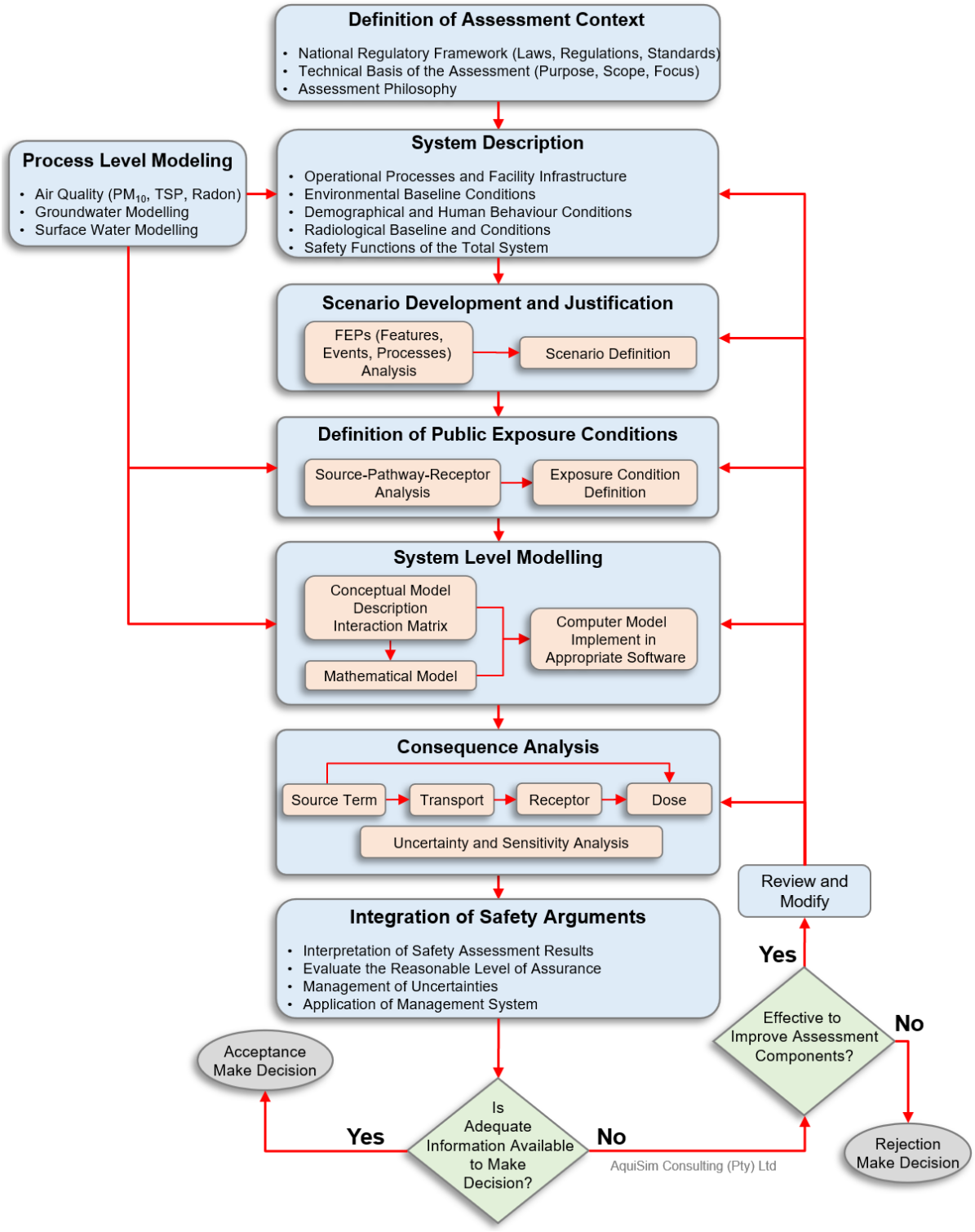


Figure 1.5 **Schematic illustration of the conceptual assessment framework used to perform the radiological public safety assessment of the Project.**

- Section 4 presents a discussion of the conditions of public exposure considered for the safety assessment of the Project. The section follows a source-pathway-receptor analysis approach, using system descriptions as a basis for deriving and justifying a discrete set of public exposure conditions for the Project.

- Section 5 assesses the potential radiological consequences of the public exposure conditions defined for the Project, including the calculation of total effective doses and a discussion of the results in terms of regulatory compliance criteria.
- Section 6 evaluates the sensitivity of the assessment results to variations in conditions and parameter values used in the consequence analysis.
- Section 7 presents the arguments supporting the impact assessment for the Project.
- Section 8 presents the proposed radiation monitoring programme for the Project.
- Section 9 presents overall conclusions and recommendations for improving public radiation safety based on the safety assessment of the Project.

2 Assessment Context

2.1 General

Within the conceptual framework presented in Figure 1.5 and consistent with the IAEA safety assessment methodology, the purpose of the assessment context is to define in simple terms the *basis* or *context* within which the Project radiological public safety assessment was conducted. Generally, it consists of a set of high-level assumptions and constraints that define the boundary conditions within which an assessment is conducted, i.e., what is included and what is excluded, along with a justification for the choices made.

The section is structured as follows. Section 2.2 defines the nuclear regulatory framework applicable to the assessment, from both national and international perspectives. In contrast, Section 2.3 presents the technical basis of the assessment, including the purpose, scope, and focus, as applicable.

2.2 Nuclear Regulatory Framework

2.2.1 General

The regulatory framework is defined by a combination of national legislation (see Section 1.3) and regulations, requirements, and guidance established under this legislation. The national framework is supplemented with principles, requirements, and guidance from international organisations concerned with radiation protection and the management of radioactive waste, including NORM. Regulations regarding safety standards and regulatory practices in South Africa were gazetted in 2006 (Regulation No. 388 dated 28 April 2006). Regulation No. 388 addresses Safety Standards and Regulatory Practices. It defines the standards and principles that must be met to ensure safety at any nuclear installation (e.g., nuclear power plants, medical facilities, research centres, and other industrial applications of radiation sources), including mineral processing facilities.

In 2013, the NNR published Regulatory Guide RG-002 entitled: "*Safety Assessment of Radiation Hazards to Members of the Public from NORM Activities*" (NNR, 2013). RG-002 provides guidelines for holders and prospective holders of NNR authorisations on conducting prior and operational public safety assessments for activities and operations involving NORM.

The international framework for radiation protection in the nuclear, medical, and mining industries is well-established and recognised. According to IAEA (2004a), organisations that play a key role in this regard include the *United Nations Scientific Committee on the Effects of Atomic Radiation* (UNSCEAR), the ICRP, and the IAEA.

The UNSCEAR mandate, established in 1955 by the United Nations General Assembly, is to assess and report on the levels and effects of ionising radiation exposure. Governments and organisations worldwide rely on the Committee's estimates as the scientific basis for evaluating radiation risk and establishing protective measures. Consequently, UNSCEAR published informative documents. Some of these publications and reports may not be directly applicable to the mining and mineral processing industry. Still, they contribute to the overall framework for protecting human health and the environment from exposure to ionising radiation.

The overall objective of the IAEA publication GSR Part 3"*Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*" (IAEA, 2014) in the General Safety Requirements series is to establish requirements (i.e. *shall* statements) for the protection of people and the environment from the harmful effects of ionising radiation and the safety of radiation sources.

2.2.2 The ICRP System of Radiological Protection

The ICRP is a non-governmental, independent, scientific organisation founded in 1928, following recommendations at the first International Congress of Radiology (ICR) held in London in 1925, to establish international protection standards (ICRP, 2009b). The ICRP has more than 200 volunteer members from approximately 30 countries across six continents, representing the world's leading scientists and policymakers in radiological protection. The ICRP is a not-for-profit organisation registered as a charity in the United Kingdom and currently has its scientific secretariat in Ottawa, Canada. They regularly publish recommendations for protection against ionising radiation (https://www.icrp.org/). The ICRP's authority derives from the scientific standing of its members and the merit of its recommendations.

Historically, the primary aim of the ICRP System of Radiological Protection is to provide an appropriate standard of protection for human beings without unduly limiting beneficial practices derived from radiological materials (ICRP, 1991). To achieve this objective, the ICRP system is intended to prevent deterministic effects by keeping doses below the relevant threshold. It also ensures that all reasonable steps are taken to minimise the induction of stochastic effects by keeping doses as low as reasonably achievable (ALARA), with economic and social factors being considered (ICRP, 2000).

The ICRP System of Radiological Protection is based on three principles. The first two principles are source-related and apply in all exposure situations, while the third principle is related to the exposure of an individual and applies in planned exposure situations (ICRP, 1991):

- **The Principle of Justification**: Any decision that alters the radiation exposure situation should do more good than harm. By introducing a new radiation source while reducing existing exposure and the risk of potential exposure, one should, therefore, achieve sufficient individual or societal benefit to offset the detriment it causes.
- **The Principle of Optimisation of Protection**: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors.
- **The Principle of Application of Dose Limits**: The total dose to any individual from regulated sources during planned exposure situations (excluding medical exposure of patients) should not exceed appropriate limits.

In its revised System of Protection, the ICRP recognises three types of exposure situations, intended to cover the entire range of possible exposure situations (ICRP, 2007). These are:

- **Planned Exposure Situations**: Planned exposure situations involve the deliberate introduction and operation of radiation sources, which may result in anticipated (normal) exposures and unanticipated (potential) exposures.
- **Emergency Exposure Situations**: Emergency exposure situations are unexpected events that may occur during the execution of a planned operation, resulting from a malicious act or other unforeseen circumstances, requiring urgent action to prevent or mitigate adverse consequences.
- **Existing Exposure Situations**: Existing exposure situations are those in which exposure already exists when a control decision must be made, including prolonged exposure following emergencies or resulting from natural background radiation.

The principles of *justification* and *optimisation* apply to all three exposure situations. In contrast, the principle of *applying dose limits applies only to doses expected to be incurred with certainty in* planned exposure situations. The principle of *justification* requires that the net benefit of any radiation-related action be positive. The Project falls under the *Planned Exposure Situation* category.

2.2.3 The IAEA Safety Standards

The status of the IAEA safety standards derives from the IAEA's Statute that authorises the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialised agencies concerned, standards of safety for protection of human health and minimisation of danger to life and property, and to provide for their application.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionising radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Figure 2.1): safety fundamentals, safety requirements and safety guides. Figure 2.2 presents the long-term general structure of the IAEA Safety Standards (IAEA, 2011).

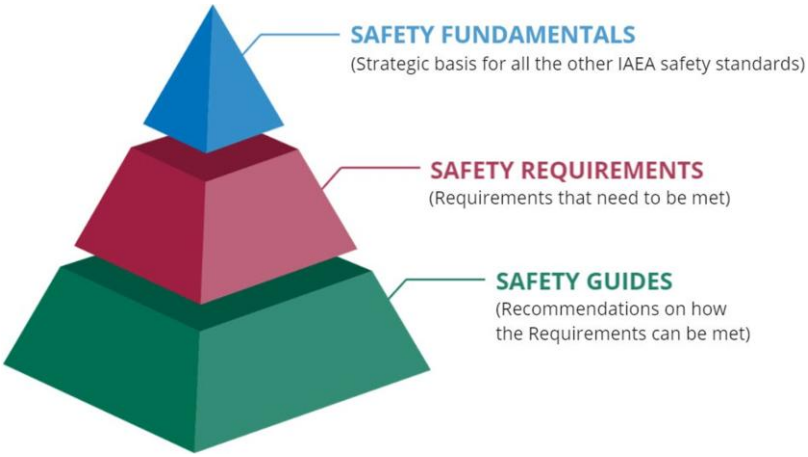


Figure 2.1 Hierarchy of the IAEA safety standards consisting of safety fundamentals, safety requirements and safety guides.

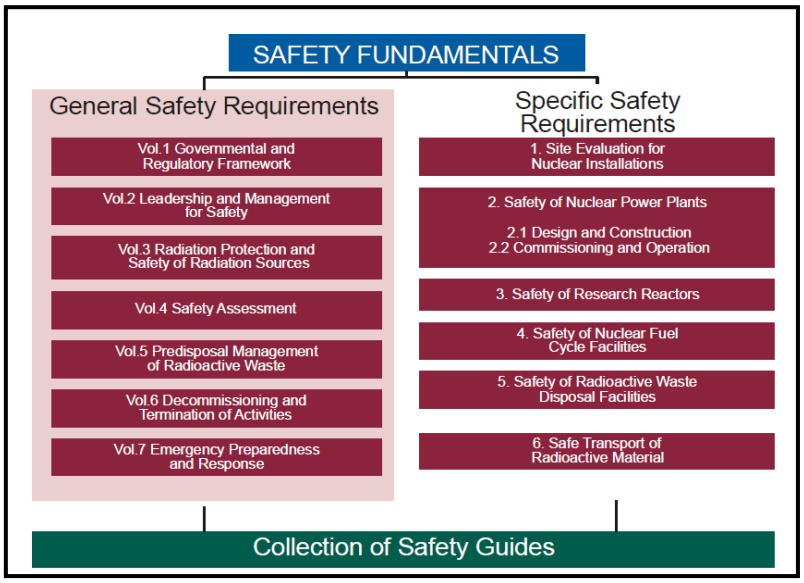


Figure 2.2 The long-term structure of the IAEA Safety Standards (IAEA, 2011).

The Safety Fundamentals present the fundamental safety objective and principles of protection and safety, providing the basis for the Safety Requirements. The principles are expressed as 'must' statements. The objective and principles of the Safety Fundamentals govern Safety Requirements. They establish the requirements to protect people and the environment, now and in the future. The format and style of the

Safety Requirements facilitate their use in establishing a national regulatory framework. Requirements are presented as 'overarching' requirements in bold, followed by several associated requirements; all are equally important and are expressed as 'shall' statements. The General Safety Requirements (GSRs) are published in seven parts and apply to all facilities and activities with a graded approach. The Specific Safety Requirements (SSRs) apply to specific facilities and activities.

Safety Guides provide recommendations for complying with the Safety Requirements, indicating an international consensus that the recommended measures (or alternative measures that achieve the same level of protection) should be implemented. Safety Guides present international good practices and, increasingly, best practices. General Safety Guides (GSGs) apply to all facilities and activities, whereas Specific Safety Guides (SSGs) apply to specific facilities and activities. The recommendations provided in Safety Guides are expressed as 'should' statements.

2.2.4 International Basic Safety Standards (GSR Part 3) (IAEA, 2014)

The overall objective of the IAEA publication GSR Part 3 "*Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*" (IAEA, 2014) in the General Safety Requirements series is to establish requirements (i.e. *shall* statements) for the protection of people and the environment from the harmful effects of ionising radiation and the safety of radiation sources. Section 1 does not constitute requirements but explains the context, concepts and principles for the requirements presented in the remainder of the document. These include (amongst others) the following:

- The *System of Protection and Safety* is based on the IAEA Fundamental Safety Principles outlined in IAEA (2006).
- The *Types of Exposure Situations* that, in their definition, are consistent with the ICRP exposure situations (ICRP, 2007) introduced in Section 2.2.2.
- An explanation of the concepts of *Dose Constraints and Reference Levels*. Both concepts are used to optimise protection and safety, to control all exposures to levels as low as reasonably achievable (ALARA) while taking economic, societal, and environmental factors into account.
- *Protection of the Environment*, which recognised the need to assess environmental protection while allowing flexibility in incorporating environmental assessment results into decision-making processes, commensurate with radiation risks.
- *The Interface between Safety and Security*, both of which aim to protect human life, health, and the environment. Additionally, safety and security measures must be designed and implemented in an integrated manner, ensuring that neither compromises the other.

The requirements specified in Section 2 to Section 5 distinguish among the three types of exposure situations, with further distinctions among occupational, public, and medical exposures.

2.2.5 Safety Standards for the Protection of the Public

To avoid severely inequitable outcomes in the optimisation procedure, restrictions should be imposed on the doses or risks imposed on individuals from a source. Regulatory tools used to reduce risk include *dose or risk constraints* and *reference levels*.

In planned exposure situations, the ICRP recommends that public exposure be controlled by optimisation procedures below the source-related constraint and by dose limits. In an emergency or existing exposure situation, the ICRP uses the term 'reference level' for the restriction on dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimisation of protection should be implemented.

The ICRP recommends that any exposure caused by human activity above natural background radiation should be kept as low as reasonably achievable (ALARA), with economic and social factors being taken into account, but below the following individual dose limits (ICRP, 1991):

- The individual dose limit for public exposure in planned exposure situations is 1 mSv per year.
- In special circumstances, an effective dose of up to 5 mSv in a single year may be applied, provided that the average dose over five consecutive years does not exceed 1 mSv per year.
- Also, the ICRP recommends equivalent dose limits of 15 mSv per year to the lens of the eye and 50 mSv per year to the skin.

The dose limits for public exposure are presented in Schedule III of GSR Part 3 (IAEA, 2014) and are consistent with the limits defined in ICRP (1991):

- An effective dose of 1 mSv in a year.
- In special circumstances (e.g., authorised, justified, and planned operational circumstances that lead to transitory increases in exposure), a higher effective dose in a single year may apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year.
- An equivalent dose to the lens of the eye of 15 mSv in a year.
- An equivalent dose to the skin of 50 mSv in a year.

The ICRP further recommends that consideration must be given to the presence of other sources that may cause simultaneous radiation exposure to the same group of the public. Allowance for future sources must be accounted for to ensure that the total dose received by an individual member of the public does not exceed the dose limit. For this reason, *dose constraints* below the dose limit, typically 0.1 to 0.3 mSv per year, are proposed to ensure that the annual dose does not exceed 1 mSv. Dose constraints are thus set separately for each source under control and serve as boundary conditions in defining the range of optimisation options.

Note that a *dose constraint is not a dose limit*; *exceeding a dose constraint does not represent non-compliance with regulatory requirements*, but could result in follow-up actions as required by the regulatory body (IAEA, 2014).

The 1 mSv per year criterion adopted in South Africa under Regulation No. 388 for public protection is therefore consistent with ICRP and IAEA recommendations on public exposure. The Regulation No. 388 dose constraint of 0.25 mSv per year for public exposure per CoR holder is also within the 0.1 to 0.3 mSv per year range proposed by the ICRP and the IAEA.

2.2.6 National Radioactive Waste Management Policy and Strategy

The purpose of the National Radioactive Waste Management Policy and Strategy (NRWMP), published in 2005 (DME, 2005), is:

> *To ensure the establishment of a comprehensive radioactive waste governance framework by formulating, in addition to nuclear and other applicable legislation, a policy and implementation strategy in consultation with all stakeholders.*

Within the national framework, the NRWMP serves as the starting point for defining and selecting an appropriate radioactive waste management solution.

The NRWMP also addresses options for managing radioactive waste generated through the nuclear industry, as well as waste containing unconcentrated naturally occurring radioactive materials from the

mining and minerals processing industries. In considering options for radioactive waste management, the document takes cognisance of the IAEA's radioactive waste management principles (IAEA, 1995). To guide the national strategy for radioactive waste management, several key reference points are defined. Two of the guiding principles that are of importance in terms of managing NORM are Principle No. 4 and Principle No. 13 (DME, 2005):

> *The aim (of a radioactive waste management strategy) shall be to achieve a maximum degree of passive safety in storage and disposal (Principle No. 4). The deliberate dilution of radioactive waste is not acceptable, however, in the case of NORM waste, the dilution of higher concentration material with lower concentration material will be considered if all relevant regulatory concerns are addressed (Principle No. 13).*

In implementing the NRWMP, South Africa followed the IAEA guidelines regarding the definition and classification of radioactive waste as presented in IAEA (1994) (unless deviations therefrom can be justified).

Table 2.1 summarises the waste classification scheme adopted for this purpose. Note that when the NRWMP was drafted in 2005, the waste classification scheme was in line with the IAEA waste classification scheme applicable at the time (IAEA, 1994). The IAEA classification scheme has subsequently been revised and is presented in IAEA (2009b).

The NRWMP provides several options for NORM management. The options available depend on the NORM classification: low activity (long-lived radionuclide concentration < 100 Bq.g^{-1}) or enhanced activity (long-lived radionuclide concentration > 100 Bq.g^{-1}). Table 2.2 summarises the available management options for each class of NORM waste.

Table 2.1 Summary of the National Radioactive Waste Classification Scheme (DME, 2005).

Waste Class	Waste Description	Waste type / Origin	Waste Criteria	Generic waste treatment / conditioning requirements [1]	Disposal / Management Options
1 HLW	Heat generating radioactive waste with high long and short-lived radionuclide concentrations.	1 Used fuel declared as waste or used fuel recycling products 2 Sealed sources	1 Thermal power > 2 kW/m^3. **OR** 2 Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels > levels specified for LILW-LL 3 **OR** Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) above 100 mSv per annum	Waste package suitable for handling, transport and storage (storage period in the order of 100 years). The waste form shall be solid with additional characteristics as prescribed for a specific repository.	1 (a) Regulated deep disposal (100's of metres). (b) Reprocessing, Conditioning and Recycling (c) Long Term Above Ground Storage
2 LILW-LL	Radioactive waste with low or intermediate short-lived radionuclide and intermediate long-lived radionuclide concentrations.	1 Irradiated uranium (isotope production). 2 Un-irradiated uranium (nuclear fuel production). 3 Fission and activation products (nuclear power generation and isotope production) 4 Sealed sources.	1 Thermal power (mainly due to short-lived radio nuclides (T ½ < 31 y) < 2 kW/m^3) **AND** 2 Long-lived radio nuclides (T ½ > 31 y) concentrations. ❖ Alpha: < 4000 Bq/g ❖ Beta and gamma: < 40000 Bq/g (Maximum per waste package up to 10x the concentration levels specified above). **OR** 3 Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) between 10 and 100 mSv per annum	Waste package suitable for handling, transport and storage (storage period in the order of 50 years). The waste form shall be solid with additional characteristics as for a specific repository.	1 Regulated medium depth disposal (10's of metres). 2 Managed as NORM-E waste (un-irradiated uranium)

Waste Class	Waste Description	Waste type / Origin	Waste Criteria	Generic waste treatment / conditioning requirements [1]	Disposal / Management Options
3 LILW-SL	Radioactive waste with low or intermediate short-lived radionuclide and / or low long-lived radionuclide concentrations.	1 Un-irradiated uranium (nuclear fuel production). 2 Fission and activation products (nuclear power generation and isotope production. 3 Sealed sources.	1 Thermal power (mainly due to short-lived radio nuclides ($T_{½}$ < 31 y) < 2 kW/m^3. **AND** 2 Long-lived radio nuclide ($T_{½}$ > 31 y) concentrations. ❖ Alpha: < 400 Bq/g ❖ Beta and gamma: < 4000 Bq/g (Maximum per waste package up to 10x the concentration levels specified above). 3 **OR** Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) below 10 mSv per annum	Waste package suitable for handling, transport and storage (storage period in the order of 10 years). The waste form shall be solid with additional characteristics as for a specific repository.	1 Regulated near surface disposal (< 10 metres). 2 Managed as NORM-E waste (un-irradiated uranium)
4 VLLW	Radioactive waste containing very low concentration of radioactivity.	1 Contaminated or slightly radioactive material originating from operation and decommissioning activities.	1 Clearance or authorised discharge or reuse criteria and levels approved by the relevant regulator.	Waste stream specific requirements and conditions.	1 Clearance. 2 Authorized disposal, discharge or reuse
5 NORM-L (low activity)	Potential Radioactive waste containing low concentrations of NORM.	1 Mining and minerals processing. 2 Fossil fuel electricity generation. 3 Bulk waste - un-irradiated uranium (Nuclear fuel production).	1 Long-lived radio nuclide concentration: < 100 Bq/g.	Unpackaged waste in a miscible waste form.	1 Re-use as underground backfill material in an underground area. 2 Extraction of any economically recoverable minerals, followed by disposal in any mine tailings dam or other sufficiently confined surface impoundment 3 Authorised disposal 4 Clearance
6 NORM-E (enhanced activity)	Radioactive waste containing enhanced concentrations of NORM.	1 Scales 2 Soils contaminated with scales	1 Long-lived radio nuclide concentration: > 100 Bq/g.	Packaged or unpackaged waste in a miscible or solid form with additional characteristics for a specific repository.	1 Dilute and re-use as underground backfill material in an identified 2 underground area. Extraction of any economically recoverable minerals, followed by dilution and disposal in an identified mine tailings dam or other 3 sufficiently confined surface impoundment Regulated deep or medium depth disposal.

[1] Treatment and conditioning requirements are mainly dependant on specific waste type in a waste class.

Table 2.2 Management options for low activity NORM and enhanced activity NORM, as defined in DME (2005).

Low Activity NORM (less than 100 Bq.g^{-1})	Enhanced Activity NORM (more than 100 Bq.g^{-1})
Re-use NORM as an underground backfill material in an underground area	
Extraction of any economically recoverable minerals from the NORM, followed by disposal in any mine tailings dam or another sufficiently confined surface impoundment	
Authorised disposal	Regulated deep or medium-depth disposal
Clearance	

Note that at the time (in 2005) when the Policy and Strategy were drafted, the waste classification scheme was in line with the IAEA waste classification scheme (IAEA, 1994). The IAEA classification scheme has subsequently been revised (IAEA, 2009b).

2.2.7 Waste Categorisation for Mining and Mineral Processing Facilities

The waste categorisation scheme for mining and mineral processing facilities distinguishes between *non-process waste* (waste for which it is considered unlikely that any radioactive contamination occurred) and *process waste*. For *process waste*, there is a potential risk that it may have become radioactively contaminated, either directly through involvement in a process known to be radioactively contaminated, or indirectly by being near known or potentially radioactively contaminated waste. *Homogeneous Process Waste* refers to *process waste* in bulk or homogeneous form, including materials such as tailings, pyrite, baddeleyite, and calcine. Table 2.3 summarises the categorisation of homogeneous process waste and associated management options.

Note that the proposed management strategy for Category III waste (more than 1,000 Bq.g^{-1}) is still storage at a licensed site in an approved storage facility, since a long-term (permanent) solution for managing this waste (i.e., high-level waste) is not available in South Africa at present.

Table 2.3 The categorisation of homogeneous process waste and associated management options.

Category	Description	Disposal/Storage Option
Category I	Waste with a specific alpha activity (U-238, U-234, Th-230, Ra-226, Po-210, Th-232, and Th-228) not exceeding 100 Bq.g^{-1}	• Released to a licensed facility. • Stored on site. • Placed directly on TSFs or WRDs
Category II	Waste with a specific alpha activity (U-238, U-234, Th-230, Ra-226, Po-210, Th-232, and Th-228) exceeding 100 Bq.g^{-1}, but not exceeding 1,000 Bq.g^{-1}	• Released to a licensed facility. • Stored on site. • Placed directly on a TSF or WRD following a process of dilution of at least 1:10
Category III	Waste with a specific alpha activity (U-238, U-234, Th-230, Ra-226, Po-210, Th-232, and Th-228) exceeding 1,000 Bq.g^{-1}	• Stored on a licensed site in an approved storage facility until a final disposal option is available

2.3 Technical Basis of the Assessment

2.3.1 General

A radiological public safety assessment can serve multiple purposes within the overall management of an operation, facility, or activity. As the operation, facility, or activity moves through the pre-operational, operational, and post-closure phases, the purpose, scope, and focus of these assessments may vary. Before operations commence, a prospective pre-operational safety assessment is conducted to determine whether the proposed operations do not pose a radiological risk to workers and the public above the applicable regulatory compliance criteria. Once operational, the prospective assessment is updated with a facility and site-specific safety assessment, as appropriate.

The purpose of this section is to define the technical basis of the assessment, which is broadly defined by the purpose, scope and focus of the assessment, but *inter alia* the spatial and temporal boundary conditions and associated assessment endpoints.

2.3.2 Interested Parties to the Assessment

A radiological safety assessment is generally undertaken to provide confidence to interested parties that an operation, facility or activity does not pose a radiological risk to relevant exposure groups, notably workers or members of the public. As used here, interested parties are groups or individuals with an interest in the radiological safety of an existing or proposed operation, facility or activity. In some cases, these groups may have specific interests that affect the assessment's purpose, scope, and focus, leading to additional assessment endpoints to consider or considerations for how the assessment results are presented. For this reason, the list of interested parties must be included in the technical basis section of the assessment context report.

Generally, the interested parties include management and technical staff responsible for the design, implementation, and operation of facilities or activities; regulatory authorities; workers; members of the public; and environmental and human rights groups.

Viewed from this perspective, the main interested parties or target audience include the following:

- Regulatory authorities that include the NNR as a statutory body responsible for regulating NORM and that is responsible for monitoring the process to ensure that the operational activities are performed by following relevant regulatory guidance and requirements;
- Workers at Harmony, and more specifically, those who are responsible and involved in the implementation of the Project;
- Members of the public living near the Project, which may potentially be affected by the facilities and activities associated with the Project (e.g., ward councillors, labour unions, agriculture, and landowners);
- Mining and industry, particularly the mining and mineral processing operations near the Project;
- Officials from the Local, Provincial and National Government Departments that will be responsible for evaluating the applications for environmental authorisation and have to ensure that the environmental investigations are performed by following relevant regulatory guidance and requirements; and
- Technical, scientific, and environmental groups interested in the assessment approach and its outcomes.

2.3.3 Purpose and Objectives of the Assessment

Companies planning to develop mining or mineral processing operations must undergo a thorough permitting process to assure regulators and stakeholders that their facilities can be safely constructed, operated, decommissioned, and closed without posing risks to workers and public health, nearby communities, or the environment (Chambers *et al.*, 2012). A critical component of this process is the radiological public safety assessment, which evaluates the system's performance, including mining or processing operations, and their impacts. The assessment measures radiological safety based on the total effective dose received by workers and the public (IAEA, 2007).

The nuclear regulatory framework (see Section 2.2) clearly outlines the overarching safety objective (IAEA, 2006) and the necessity of safeguarding human health and the environment over relevant timescales for all facilities and activities, including mining and mineral processing operations (IAEA, 2009a; ICRP, 2000). Such assessments are mandated for both new and existing facilities and activities. From a radiological safety perspective and complemented with the ESHIA requirements, the purpose of the radiological safety and impact assessment as input into the ESHIA process is, therefore, twofold:

- To evaluate and demonstrate that members of the public living near the Project will not be exposed to levels of ionising radiation released to the environment above the regulatory compliance criteria set for public exposure as defined in Section 2.2.3.
- To assess the radiological impact on members of the public living near the Project as input into the ESHIA process. The basis for the impact assessment is the outcome of the radiological public safety assessment, and the assessment is conducted in accordance with the criteria specified in Section 2.3.7.3.

2.3.4 Scope and Focus of the Assessment

2.3.4.1 General

The Project comprises, first, the removal of existing facilities and, second, the construction of a new TSF facility. For this purpose, an ACR for CoR-28 is required to be submitted to the NNR (see Section 1.3).

2.3.4.2 Natural Background Radiation

This assessment focuses on evaluating radiation exposure induced by the Project, specifically above the natural background radiation, as introduced in Section 1.2. Since natural background radiation is not subject to regulatory control, it is excluded from comparisons of the total effective dose against regulatory compliance criteria.

The approach used in this assessment involves determining the source term (or release rate) of radioactivity from the Project facilities to the environment, estimating how released radioactivity disperses, and assessing how members of the public interact with the affected environmental media, thereby determining their total effective dose. When necessary and justified, this approach is supplemented by direct environmental measurements to quantify the potential contribution to the public dose.

2.3.4.3 Site-Specific Assessment

The radiological public safety assessment relies primarily on site-specific data, where feasible and justifiable. When necessary, this site-specific data is supplemented with values from literature or analogous facilities, such as those related to the Project. All assumptions and conditions used in the assessment are thoroughly documented and justified.

2.3.4.4 Sources of Radiation Exposure

Generally, mining and mineral processing operations may involve multiple sources of radiation exposure that must be considered holistically within the radiological public safety assessment. These sources include releases to the atmospheric and aquatic pathways from the processing plant (e.g. stacks), ventilation shafts, residue management facilities (e.g., waste rock dumps, tailings storage facilities), and various water management facilities.

The scope and focus of this assessment are limited to the Project and the associated facilities (e.g., the TSFs, Return Water Dams and other associated water management infrastructure) and to the potential radiological impact on members of the public.

2.3.4.5 Ionising Radiation Exposure Assessment

Mining, mineral handling, and processing activities can pose hazards to humans and the environment, not only from naturally occurring radioactivity but also from toxic elements and compounds present in

products, by-products, residues, and wastes generated by these activities. The radiological public safety assessment focuses specifically on exposure to ionising radiation. It does not address health risks related to non-ionising radiation, non-radioactive substances or other health and safety concerns.

2.3.4.6 Contaminants of Concern

The contaminants of concern in the radiological assessment are naturally occurring radionuclides from the uranium and thorium decay series. Table A 1 to Table A 3 list these series and their radiological properties, while Figure A 1 is a schematic illustration of the decay series (see Appendix A).

Uranium, a dense metallic element, occurs in Earth's crust at an average concentration of 3 ppm and comprises the isotopes U-238, U-235, and U-234. U-238 and U-235 are the parent isotopes in two separate decay series, while U-234 is a decay product of U-238. Thorium-232 (Th-232) also has a decay series, which is often included in assessments of naturally occurring radionuclides. Thorium is more abundant than uranium and occurs as black thorium oxide.

Exposure to uranium, thorium, and their decay products can have harmful health effects, mainly due to the ionising radiation they emit. Epidemiological studies have shown a link between these exposures and health issues (Klaassen, 2001), although not all radionuclides in these decay chains contribute equally to the total radiation dose. Only radionuclides that significantly contribute to the effective dose are considered in the assessment, with specific dose conversion factors and half-lives taken into account. The radioactive decay and ingrowth of daughter products are accounted for in the assessment to prevent overly conservative results and to capture their long-term effects. Some radioisotopes in these decay chains remain a concern for thousands of years. Table 2.4 outlines the radionuclides explicitly considered in the Project RPSA.

Table 2.4 List of α- and β-emitting radionuclides explicitly considered in the Project Radiological Public Safety Assessment.

Long-lived Alpha (α) Radiation Emitters	Beta (β) Radiation Emitters
U-238, U-234, Th-230, Ra-226, Po-210	Pb-210
U-235, Pa-231, Ra-223	Ac-227
Th-232, Th-228, Ra-224	Ra-228

Secular equilibrium is assumed between parent and daughter products when analytical data for the progeny are unavailable. In the absence of direct measurements of the daughter products, it is, therefore, assumed that the parent and its decay products exist in a state of equilibrium, where the rate of decay of the parent is equal to the rate of decay of the daughter products. For these conditions, the following assumptions apply:

- Po-210 = Pb-210 = Ra-226 = Th-230 = U-234 = U-238.
- Ra-224 = Th-228 = Ra-228 = Th-232.
- Ra-223 = Ac-227 = Pa-231 = U-235.

2.3.4.7 Cumulative Effect

The ICRP principles and IAEA safety standards set limits to protect human health and the environment from radiation exposure, covering all radiation sources and practices. These limits apply to the cumulative radiation exposure from all contributing operations near the Project.

The focus of this assessment is specifically on the radiological contribution from the Project to the annual effective dose to members of the public. While other operations in the area may also contribute to radiation

exposure, the scope of this assessment does not extend to a regional radiological safety evaluation. However, the assessment acknowledges the potential contribution of these and other operations to the total effective dose and incorporates this into the regulatory dose constraint.

2.3.4.8 Worker Safety Assessment

The NNRA and related national safety standards require the protection of both workers (occupational exposure) and the public from ionising radiation. To comply with these requirements, safety assessments for both worker and public exposure must be submitted to the NNR. This assessment focuses explicitly on radiological safety and its impact on members of the public. A separate report documenting worker exposures associated with the Project has been prepared and submitted to the NNR.

2.3.4.9 Assessment of Non-Human Biota

The ICRP introduced the concept of establishing dose limits for non-human biota in Publication 103 (ICRP, 2008) and Publication 108 (ICRP, 2009a). A radiation assessment of non-human biota focuses on evaluating the effects of radiation on ecosystems, including animals, plants, and microorganisms, rather than on human populations. This assessment aims to understand how ionising radiation affects different species by determining radiation dose rates, identifying exposure pathways (e.g., ingestion, inhalation, and direct radiation), and comparing these doses to established threshold levels for ecological protection. The goal is to ensure that radiation remains within safe limits to prevent adverse effects on biodiversity and ecosystem functions. Historically, it was assumed that protecting humans from radiation also protected non-human biota at the species level (ICRP, 1991).

One recognised method for assessing the impacts on non-human biota is the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA), which uses the ERICA software tool. This tool accounts for radionuclide concentrations across media and species-specific concentration ratios to standardise the measurement of radiological impact on reference species.

While environmental protection is a key principle in IAEA safety standards, the scope of the current assessment excludes the consideration of non-human biota. Furthermore, the NNR regulatory framework does not require the evaluation of non-human biota at this time.

2.3.4.10 Human Behavioural Conditions and Age Groups

The assessment considers, to the extent possible, site-specific human behavioural conditions observed near the Project and justifies the definition of a discrete set of public exposure conditions (see Section 4) for all relevant age groups. Consistent with the guidance provided in RG-002 (NNR, 2013), the assessment considers the age groups and age ranges listed in Table 2.5.

Table 2.5 Age group ranges applicable to age-dependent dose conversion factors as published in RG-002 (NNR, 2013).

Ages specified in RG-002	Applicable Age Range	Age Group Used in the Assessment
New-born	From 0 to 1 year of age	0 to 2 years
1 Year	From 1 year to 2 years	
5 Year	More than 2 years to 7 years	2 years to 7 years
10 Year	More than 7 years to 12 years	7 years to 12 years
15 Year	More than 12 years to 17 years	12 years to 17 years
Adult	More than 17 years	Adults

2.3.5 Spatial Domain of Concern

The spatial domain for the radiological public safety assessment is primarily determined by understanding the processes governing radionuclide transport and the potential exposure pathways for at-risk exposure groups. While physical boundaries cannot be applied uniformly across all processes, a 3 to 5 km radius around environmental release points is often sufficient for evaluating environmental pathways. If necessary, a broader study area may be established to account for processes that affect radionuclide movement beyond this range. Since the analysis focuses on critical groups, exposure locations are expected to be close to the sources, thereby constraining the assessment's spatial scale to the selected public exposure conditions.

2.3.6 Assessment Timescales

The lifecycle of a typical mining operation is divided into three distinct phases: the pre-operational phase (including design, construction, and commissioning), the operational phase, and the post-operational (or post-closure) phase. The operational and post-operational phases are when conditions that could lead to the dispersion of NORM into the environment and public exposure are most likely to occur.

The assessment of potential radiological impacts during the operational phase is more certain because current or near-future conditions can be reliably predicted. In contrast, conditions during the post-operational phase are more uncertain, and the assessment must account for these uncertainties. As a result, the radiological public safety assessment primarily focuses on the operational phase, while also addressing potential radiological impacts during the post-operational phase to the extent feasible and justified.

2.3.7 Assessment Endpoint

2.3.7.1 General

The regulatory framework determines the assessment (or calculation) endpoints for a radiological public safety assessment, as well as its purpose, scope, and focus. In some cases, the target audience or stakeholders may identify additional assessment endpoints. While quantitative endpoints are most commonly used in safety assessments, qualitative endpoints may also be required.

2.3.7.2 Radiological Public Safety Assessment Endpoints

The focus of the radiological public safety assessment is the radiological impact on members of the public in the vicinity of the Project area (see Section 2.3.4). More specifically, the objective is to quantify the release and subsequent distribution of radioactivity into and through the environment, and the subsequent interactions of members of the public with potentially affected environmental media.

Consistent with the ICRP System of Protection defined in Section 2.2.3, the primary assessment endpoint for radiological public safety assessment is the annual individual effective dose rate. Unless otherwise stated, the term dose refers to the annual individual effective radiation dose to members of the public, calculated using the method described in ICRP (1991), which is consistent with the NNR requirements for the radiological protection of members of the public and adopted in the Safety Standards and Regulatory Practices presented in Regulation No. 388.

2.3.7.3 ESHIA Criteria

The following EIMS methodology and rationale are used to assess the significance of the potential impacts of the final site layout plan on the surrounding biophysical and socio-economic environment. The requirements of the NEMA ESHIA Regulations guide the impact assessment methodology. The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (Nature, Extent, Duration, Magnitude, and Reversibility) and relating it to the probability/likelihood (P) of the impact occurring. This determines the environmental risk. In addition, other factors, including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF), which is applied to the ER to determine the overall significance (S). The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER). The environmental risk depends on the impact's consequences (C) and the probability (P) that the impact occurs. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and Reversibility (R) applicable to the specific impact. For this methodology, the consequence of the impact is represented by:

$$C = \frac{(E + D + M + R) \cdot N}{4}$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 2.6. Once the consequence has been determined, the ER is determined following the standard risk assessment relationship by multiplying the C and the P. Probability is rated/scored as per Table 2.7. The result is a qualitative representation of the relative ER associated with the impact.

Table 2.6 Criteria used to determine the impact consequence.

Aspect	Score	Definition
Nature	- 1	Likely to result in a negative/ detrimental impact
	+1	Likely to result in a positive/ beneficial impact
Extent	1	Activity (i.e., limited to the area applicable to the specific activity)
	2	Site (i.e., within the development property boundary)
	3	Local (i.e., the area within 5 km of the site)
	4	Regional (i.e., extends between 5 and 50 km from the site)
	5	Provincial / National (i.e., extends beyond 50 km from the site)
Duration	1	Immediate (<1 year)
	2	Short-term (1-5 years)
	3	Medium-term (6-15 years)
	4	Long-term (the impact will cease after the operational life span of the project)
	5	Permanent (no mitigation measure or natural process will reduce the impact after construction)
Magnitude/ Intensity	1	Minor (where the impact affects the environment in such a way that natural, cultural, and social functions and processes are not affected)
	2	Low (where the impact affects the environment in such a way that natural, cultural, and social functions and processes are slightly affected)
	3	Moderate (where the affected environment is altered but natural, cultural, and social functions and processes continue, albeit in a modified way)
	4	High (where natural, cultural, or social functions or processes are altered to the extent that they will temporarily cease), or
	5	Very high / do not know (where natural, cultural, or social functions or processes are altered to the extent that they will permanently cease)
Reversibility	1	The impact is reversible without any time or cost
	2	The impact is reversible without incurring significant time and cost
	3	The impact is reversible only by incurring significant time and cost
	4	The impact is reversible only by incurring prohibitively high time and cost
	5	Irreversible Impact

Table 2.7 Probability scoring.

Aspect	Score	Definition
Probability	1	Improbable (the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <25%)
	2	Low probability (there is a possibility that the impact will occur; >25% and <50%)
	3	Medium probability (the impact may occur; >50% and <75%)
	4	High probability (it is most likely that the impact will occur- > 75% probability), or
	5	Definite (the impact will occur)

ER is therefore calculated as follows (see Table 2.8):

$$\boldsymbol{ER = C \cdot P}$$

The environmental risk assessment will yield scores from 1 to 25. These ER scores are then grouped into respective classes as described in Table 2.9. The impact ER will be determined for each impact without relevant management and mitigation measures (pre-mitigation), as well as post-implementation of relevant management and mitigation measures (post-mitigation). This allows prediction of the extent to which the impact can be managed/mitigated.

Table 2.8 Determination of environmental risk.

Consequence						
	5	**5**	**10**	**15**	**20**	**25**
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
		Probability				

Table 2.9 Significance classes.

Environmental Risk Score	
Value	Description
< 9	Low (i.e., where this impact is unlikely to be a significant environmental risk)
≥9; <17	Medium (i.e., where the impact could have a significant environmental risk)
≥ 17	High (i.e., where the impact will have a significant environmental risk)

Following the requirements of Appendix 3(3)(j) of the NEMA 2014 EIA Regulations (GN R. 982), and further to the assessment criteria presented above, it is necessary to assess each potentially significant impact in terms of:

- Cumulative impacts.
- The degree to which the impact may cause irreplaceable loss of resources.

In addition, public opinion and sentiment regarding a prospective development and consequent potential impacts must be considered in the decision-making process.

To ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation) (see Table 2.10). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the decision-making authority's attention on higher-priority/significance issues and impacts. The PF will be applied to the ER score, assuming that the relevant suggested management/mitigation actions are implemented.

Table 2.10 The criteria used to determine the prioritisation.

Public response (PR)	Low (1)	Issue not raised in the public response.
	Medium (2)	The issue has received a meaningful and justifiable public response.
	High (3)	The issue has received an intense, meaningful and justifiable public response.
Cumulative Impact (CI)	Low (1)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.
	Medium (2)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.
	High (3)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.
The irreplaceable loss of resources (LR)	Low (1)	Where the impact is unlikely to result in irreplaceable loss of resources.
	Medium (2)	Where the impact may result in the irreplaceable loss (cannot be replaced or substituted) of resources, but the value (services and/or functions) of these resources is limited.
	High (3)	Where the impact may result in the irreplaceable loss of resources of high value (services and/or functions).

The final impact priority is represented as a single consolidated priority, determined by summing the individual criteria in Table 2.11. The impact priority is therefore determined as follows:

$$\boldsymbol{Priority = PR + CI + LR}$$

The result is a priority score ranging from 3 to 9 and a corresponding PF ranging from 1 to 2 (see Table 2.11).

Table 2.11 Determination of prioritisation factor

Priority	Ranking	Prioritization Factor
3	Low	**1**
4	Medium	**1.17**
5	Medium	**1.33**
6	Medium	**1.5**
7	Medium	**1.67**
8	Medium	**1.83**
9	High	**2**

To determine the final impact significance, the PF is multiplied by the post-mitigation scoring ER (see Table 2.12). The ultimate aim of the PF is to be able to increase the post-mitigation environmental risk rating by a full ranking class if all the priority attributes are high (i.e., if an impact comes out with a medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential, significant public response, and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

2.3.7.4 Complementary Assessment Endpoints

A radiological public safety assessment should not rely on a single endpoint, such as an individual effective dose rate (IAEA, 1997; 2004c). Multiple lines of reasoning may be helpful and sometimes significant, since regulatory bodies and other stakeholders may use and require a wide range of arguments and endpoints to determine the adequacy of a public safety assessment.

Viewed from this perspective, activity concentrations in environmental media may serve as a complementary endpoint for assessment. While it may not be necessary for regulatory compliance,

reporting these endpoints contributes to the overall transparency of the assessment. Therefore, radionuclide concentrations in environmental media can serve as complementary safety indicators alongside the dose criterion. These may be compared with natural background concentrations in environmental media as observed near the site.

Table 2.12 Final environmental significance rating

Environmental Significance Rating	
Value	Description
< -9	Low negative (i.e., where this impact would not have a direct influence on the decision to develop in the area).
≥ -9 < -17	Medium negative (i.e., where the impact could influence the decision to develop in the area).
≥ -17	High negative (i.e., where the impact must influence the decision process to develop in the area).
0	No impact
< 9	Low positive (i.e., where this impact would not have a direct influence on the decision to develop in the area).
≥ 9 < 17	Medium positive (i.e., where the impact could influence the decision to develop in the area).
≥ 17	High positive (i.e., where the impact must influence the decision process to develop in the area).

Activity concentrations in the following environmental media may thus be reported in addition to the annual individual effective dose:

- Airborne dust activity concentration in units of $Bq.m^{-3}$ for PM_{10} (or less than 10 microns).
- Dust fallout or deposition rate in units of $Bq.m^{-2}.year^{-1}$ for Total Suspended Particulates (TSP).
- Airborne radon (or thoron) concentration in units of $Bq.m^{-3}$.
- Activity concentration in surface water or groundwater in units of $Bq.m^{-3}$ or $Bq.L^{-1}$.
- Activity concentration in surface soils in units of $Bq.kg^{-1}$.
- Activity concentration in crops (e.g., fruits, vegetables, grain, or fodder) and animal products (e.g., meat, eggs or milk) in units of $Bq.kg^{-1}$ or $Bq.L^{-1}$ for milk.

When evaluating the performance of a facility or an individual component of the total system, the release rate of radioactivity from the facility into the wider environment is also a valid criterion, particularly when containment of radioactivity is essential. These results could inform the design process to reduce the release rate, if required.

2.4 Assessment Framework and Modelling

2.4.1 General

Figure 1.5 presents the conceptual assessment framework used for the RPSA, which, as noted, is based on the IAEA ISAM methodology developed for the safety assessment of near-surface radioactive waste disposal facilities (IAEA, 2004c), with minor adaptations to better reflect mining and mineral processing operations. As shown in Figure 1.5, the framework comprises several interrelated elements, the level of detail and emphasis of which depend mainly on the technical basis of the assessment (see Section 2.3) and the overarching assessment philosophy (see Section 2.5). The development and application of models and associated modelling approaches constitute integral components of this framework.

2.4.2 Modelling Approach

2.4.2.1 General

A range of modelling approaches can be used to establish a comprehensive and defensible safety case for mining and mineral processing operations. These approaches span from simple scoping (screening) calculations to sophisticated three-dimensional modelling of environmental media. The key requirement is that the selected approaches are demonstrably fit for purpose, with due consideration of the graded approach to safety assessment (IAEA, 2012). The use of models (e.g., conceptual, mathematical, and computer models) and their associated modelling approaches is integral to the assessment framework. Figure 1.5 distinguishes between *Process Level Modelling* and *System Level Modelling*, both of which are integrated into an overall Source–Pathway–Receptor (SPR) analysis.

2.4.2.2 Process Level Modelling

Process Level modelling of significant environmental pathways is used to understand the release and subsequent migration of contaminants into and through the environment, particularly along atmospheric and aquatic (surface water and groundwater) pathways. For the atmospheric pathway, the focus is on the release and dispersion of airborne PM_{10}, total suspended particles (TSP), and, where relevant, radon gas. For aquatic pathways, the emphasis is on the flow regime and the subsequent release and transport of contaminants within the aquatic environment (i.e., advection, dispersion, and diffusion).

Process Level modelling is typically undertaken by specialists using sophisticated multidimensional numerical models to simulate the spatial and temporal distribution of particulate matter or contaminants in the environment. While this enables detailed representation of environmental processes, it also requires substantial resources to develop and operate these models. For this reason, it is often not practical to apply *Process Level Modelling* comprehensively within an integrated radiological safety assessment.

2.4.2.3 System Level Model Development

During *System Level* modelling, relevant system-scale information is abstracted from *Process Level* models, enabling the representation of an integrated system by coupling different processes so that the total contribution from all pathways can be evaluated. In practice, this involves deriving simplified descriptors from detailed atmospheric and aquatic models, for example, by abstracting results from atmospheric dispersion simulations or by simplifying groundwater flow and mass transport from 3D to an effective 1D representation.

System Level modelling typically employs compartmental models to represent the migration and fate of contaminants in the environment, thereby discretising the system into a series of compartments. It is assumed that, once a contaminant enters a compartment, instantaneous mixing occurs, yielding a uniform concentration within that compartment. Each compartment must, therefore, be defined so that this assumption is reasonably valid for the corresponding environmental component.

The use of the compartmental modelling approach further requires that the processes governing the transfer of contaminants between compartments be expressed as transfer coefficients, representing the fraction of activity in a given compartment transferred to another compartment per unit time. The mathematical representation of these inter-compartmental transfer processes is a matrix of transfer coefficients, which allows the compartmental inventories to be described by a set of coupled, first-order linear differential equations.

System Level modelling is performed using AFRY Intelligent Scenario Modelling (AISM) (Version 8.6) (https://www.intelligentscenariomodelling.com/), a commercial software package for creating dynamic models and conducting deterministic and probabilistic simulations.

2.4.2.4 Source Pathway Receptor Analysis

Consistent with the assessment framework presented in Figure 1.5, a Source-Pathway-Receptor analysis is followed to perform the safety assessment, which is well known and widely applied in environmental and radiological risk assessment as a modelling tool (Till and Grogan, 2008). If applied correctly, it quantifies the contribution of specific sources (e.g., a facility, an activity, or the entire operation), unlike an alternative approach that only samples and analyses environmental media, followed by a dose assessment. The latter does not account for the contributions from natural background radiation, sources, migration of contaminants through the environment, or associated uncertainties.

The Source-Pathway-Receptor analysis is inherently systematic, traceable and transparent, and comprises three interrelated steps to evaluate radiation exposure conditions defined for a mining and mineral processing operation.

- **Source Identification**: Identify and characterise all relevant sources of radiation exposure (current, future, and historical, if applicable). The sources are characterised by their unique composition (i.e., specific radioactive substances present or emitted) and by characteristics that determine how contaminants may be distributed in the environment.
- **Pathway Evaluation:** Evaluate all relevant pathways and routes of exposure associated with the identified sources. *Pathways* describe how radionuclides move through the environment to points of human interaction, while *exposure routes* refer to how radiation enters the human body (e.g., ingestion, inhalation, or external exposure).
- **Receptor Characterisation**: Define and evaluate potential *receptors*, i.e., humans who may be exposed to radiation (in terms of radiation dose) through the identified sources and pathways of the mining and mineral processing operation.

2.5 Assessment Philosophy

2.5.1 General

In the assessment context, *assessment philosophy* refers to the use of reasoned arguments, assumptions and lines of evidence to develop a comprehensive and defensible safety case. The assessment philosophy adopted for a given safety assessment largely determines the assessment and modelling approaches to be used, the treatment and management of uncertainties, the assumptions regarding future human behaviour, the scope and focus of sensitivity analyses, and the overall approach to building confidence in the assessment.

2.5.2 Exact Science and Safety Assessments

Radiological safety assessment is a scientific activity, but it is not an “exact science” in the narrow sense of controlled laboratory experiments where hypotheses can be directly and repeatedly tested. In classical experimental science, a working hypothesis is formulated, specific observations or experiments are designed, and the hypothesis is confirmed or falsified based on empirical results, in line with the Popperian view of science as fundamentally falsifiable. For long-term radiological safety assessments, this paradigm cannot be applied in a strict sense because the relevant system behaviour extends over time frames,

spatial scales and future conditions that are not fully accessible to direct experimentation (ICRP, 2007; Oreskes *et al.*, 1994).

The safety assessment process nonetheless draws deeply on the methods and principles of the physical and environmental sciences. Many components – such as radionuclide decay and ingrowth, hydrogeological processes, sorption and transport parameters, and dose calculation methods – are investigated using conventional scientific approaches and can be tested, calibrated and compared with observations (IAEA, 2012; ICRP, 2006). However, the integrated assessment, from the release of radionuclides through their migration in complex environmental systems to potential uptake by members of the public, involves substantial uncertainties in boundary conditions, system evolution, and future human behaviour. As a result, the overall assessment cannot be fully verified or falsified as a single hypothesis about the future (IAEA, 2012; Oreskes *et al.*, 1994).

Rather than providing exact predictions, a radiological safety assessment is best understood as a structured, transparent and traceable process for estimating and bounding potential future exposures for a defined set of scenarios, assumptions and parameter values. By examining a range of plausible and conservative conditions, assessing the sensitivity of results to key uncertainties, and drawing on multiple lines of evidence, the assessment develops a defensible understanding of the limits of potential radiological exposure for the public. This, in turn, supports the safety case by providing reasonable assurance that regulatory criteria are met and that the public will be adequately protected, even though precise statements about actual future exposures cannot be made (IAEA, 2012; ICRP, 2007).

2.5.3 Assessment Approach

Various approaches can be incorporated into the safety assessment framework to enhance the overall safety case for a mining and mineral processing operation. The following approaches can be adopted for the safety assessment:

- **Graded Approach***:* The graded approach ensures that the safety case and its supporting safety assessment are founded on an appropriate level of understanding of the overall system and its potential behaviour, and that all safety-relevant aspects are duly considered and addressed. At the same time, the resources devoted to demonstrating and ensuring safety should be commensurate with the magnitude of potential radiation risks, their controllability, and the facility's stage of development (IAEA, 2012).
- **Iterative:** The assessment framework presented in Figure 1.5 is iterative, continually improving the safety case. In practice, this means that a safety assessment would typically undergo two or more successive iterations (IAEA, 2004c). The current assessment should, therefore, be regarded as the first iteration within a broader, comprehensive assessment framework. As the assessment progresses, safety arguments can be refined and strengthened in light of experience and insights gained, thereby enhancing confidence in the overall assessment.
- **Systematic***:* The assessment framework presented in Figure 1.5 is systematic, ensuring that each stage of the assessment process, along with the associated decisions, is appropriately documented and underpinned by scientifically and technically justified methods (IAEA, 2004c).
- **Reasonable Assurance***:* The safety assessment process is not an exact procedure (see Section 2.5.2). Instead, its purpose is to arrive at defensible decisions and to identify the conditions under which reasonable assurance can be provided that the safety objectives and regulatory criteria are met.
- **Cautious vs Realistic Assumptions***:* In undertaking a safety assessment, it is necessary to adopt a

range of assumptions. *Realistic* assumptions are physically plausible and considered likely to occur, but may be difficult to substantiate fully with the available information. *Cautious* assumptions, by contrast, are not necessarily realistic but are selected to ensure that the assessment endpoint (s) are not underestimated. An appropriate balance between realistic and cautious assumptions is, therefore, sought in the assessment.

- **Transparency***:* A transparent assessment approach requires that all assumptions adopted in the assessment, as well as any constraints and conditions imposed on it, are clearly documented and communicated to all stakeholders. Transparency can be enhanced through measures such as:
  - Follow a transparent scenario (if necessary) and exposure condition development approach, including documentation and handling of expert judgement.
  - Justify and document all assumptions and constraints imposed on model development.
  - Follow a transparent approach to treat subjective uncertainties.
  - Justify and document all input parameter values used in the model development process.
- **Multiple Lines of Reasoning**: No single line of reasoning is, by itself, sufficient to establish confidence in a safety case. *Multiple lines of reasoning* are complementary arguments that draw on different approaches or sources of evidence to build confidence in the safety case. Some of these arguments may be predominantly qualitative rather than quantitative.
- **Defence in Depth**: This principle implies that the safety of the facility or operation should not rely unduly on any single safety function. Safety functions are understood as elements of the facility—such as specific physical or chemical properties of system components, or individual processes or combinations of processes—that contribute to the containment and isolation of the waste and its associated radionuclides. (IAEA, 2012).

2.5.4 Management of Uncertainty

Management of uncertainties can be viewed with four main components (Savage, 1995):

- **Awareness**: Uncertainties cannot be managed if they are unknown; therefore, a safety case and supporting safety assessment must identify all primary potential sources of uncertainty.
- **Importance**: Some uncertainties significantly affect the safety case, whereas many others are of limited importance. Before attempting to reduce uncertainties, it is necessary first to determine whether a given uncertainty has a material effect on the safety assessment's overall outcomes and conclusions. This can be evaluated, for example, through scoping calculations and sensitivity analyses.
- **Reduction**: Once the significance of particular uncertainties has been established, appropriate measures can be implemented to reduce them. The primary objective of this approach is therefore the systematic management and reduction of uncertainties.
- **Quantification**: The effects of uncertainties on the final safety assessment should be explicitly documented. Although some uncertainties are more challenging to quantify than others, it is nevertheless helpful to provide at least some quantitative consideration of key uncertainties, for example, through sensitivity and/or uncertainty analyses.

Uncertainties arise from three related sources (NEA, 1997): scenario (or future) uncertainties, model uncertainties (associated with conceptual and mathematical model development), and data/parameter uncertainties.

Subjective uncertainty is sometimes treated as a separate category, but it is, in fact, embedded within each of these types of uncertainty. It stems from the need to rely on professional judgement and expert elicitation owing to limitations in available data, incomplete knowledge of future conditions, uncertainties in conceptual models and parameter values (and their distributions), or any other aspects of the system that are not yet well understood (IAEA, 2004c).

It is not possible to draw rigid boundaries between these categories. Such uncertainties are inherent to any assessment of an environmental system, especially when long-term (post-operational) timescales are considered. Among the many judgements that must be made in the course of a safety assessment, some are not amenable to quantitative evaluation; therefore, it is necessary to address both qualitative and quantitative components of uncertainty.

2.5.5 Public Exposure Conditions

Defining the receptor population near a facility is a fundamental element of the radiological public safety assessment process. Accordingly, the characterisation and description of human behavioural conditions observed near the operation form part of the overall system description. Not all members of the population will be exposed to radiation in the same way; variations can be expected even within a given group, particularly between different age groups. These differences arise not only from varying behavioural characteristics (e.g., ingestion rates), but also from the age-dependence of dose conversion factors for ingestion and inhalation (see Table 2.5).

Where appropriate and justified, site-specific data may be supplemented with hypothetical conditions to define a critical group for the assessment. The ICRP has introduced the concept of the *Representative Person* (ICRP, 2007) as an individual whose dose is representative of the more highly exposed individuals in the population. The representative person may be hypothetical, but the habits that characterise this individual (e.g., food consumption, breathing rate, location, and use of local resources) should be typical of a small number of individuals among those most highly exposed, rather than reflecting the extreme habits of a single person. While some extreme or unusual habits may be considered, they should not determine the characteristics of the representative person. Although the exposure conditions defined for the assessment will likely include the representative person, it is essential to note that this is not necessarily the only receptor group considered. More than one receptor group may be defined, leading to different exposure conditions within the assessment.

3 System Description

3.1 Introduction

Within the conceptual framework presented in Figure 1.5, the purpose of the system description is to provide a summary overview of the Project area, with specific reference to existing and proposed facilities, activities, and associated infrastructure. This information is normally complemented with a description of the prevailing site characteristics and potentially affected human populations located near the Project area, as well as the associated radiological conditions.

The level of detail in the system description is proportional to the information required for a radiological public safety assessment. That means the system description is intended to provide a clear representation of the system features relevant to the potential impacts under evaluation and, therefore, does not necessarily require a comprehensive, detailed description of all aspects of the system.

The section is structured as follows. Section 3.2 presents the regional setting of the Project area. Section 3.3 gives an historical overview of the Kusasalethu Operations, whilst Section 3.4 describes the processes and associated infrastructure design changes, as well as the waste or by-products generated by these processes, highlighting the areas and activities that may contribute to the release and dispersion of naturally occurring radionuclides into the environment from the Project. Section 3.5 describes the water usage and management principles associated with the proposed Project. Section 3.6 summarises the baseline environmental conditions whilst Section 3.7 summarises the population characteristics observed near the Project area. Section 3.8 summarises the radiological data and information available for the Project at present.

3.2 Geographical Setting

Geographically, the Project is located in the Gauteng Province of South Africa, adjacent to the border with the Northwest Province, approximately 83 km west of Johannesburg. Figure 3.1 shows the locality of the Project.

Figure 3.2 indicates that the Project falls under the jurisdiction of the Merafong City Local Municipality (LM), which forms part of the West Rand District Municipality (DM) in Gauteng. The Merafong City Local Municipality was previously transferred from the West Rand District Municipality in Gauteng to the Southern District Municipality in the North West Province following the abolition of cross-border municipalities. However, strong objections from residents of Khutsong, near Carletonville, resulted in the municipality being reintegrated into Gauteng in April 2009.

Several communities are in proximity to the Project. Larger nearby towns include Carletonville and Fochville, located approximately 16 to 20 km from the site (AquiSim, 2023). Closer residential areas include Deelkraal, Elandsrand, and Wedela, located within approximately 3 to 4 km of the operations.

Figure 3.2 shows the Project area in relation to surrounding communities. The site is also situated adjacent to the Harmony Mponeng, Savuka, and TauTona mining complexes, which include a range of operational infrastructure, some of which lie close to the Kusasalethu boundary.

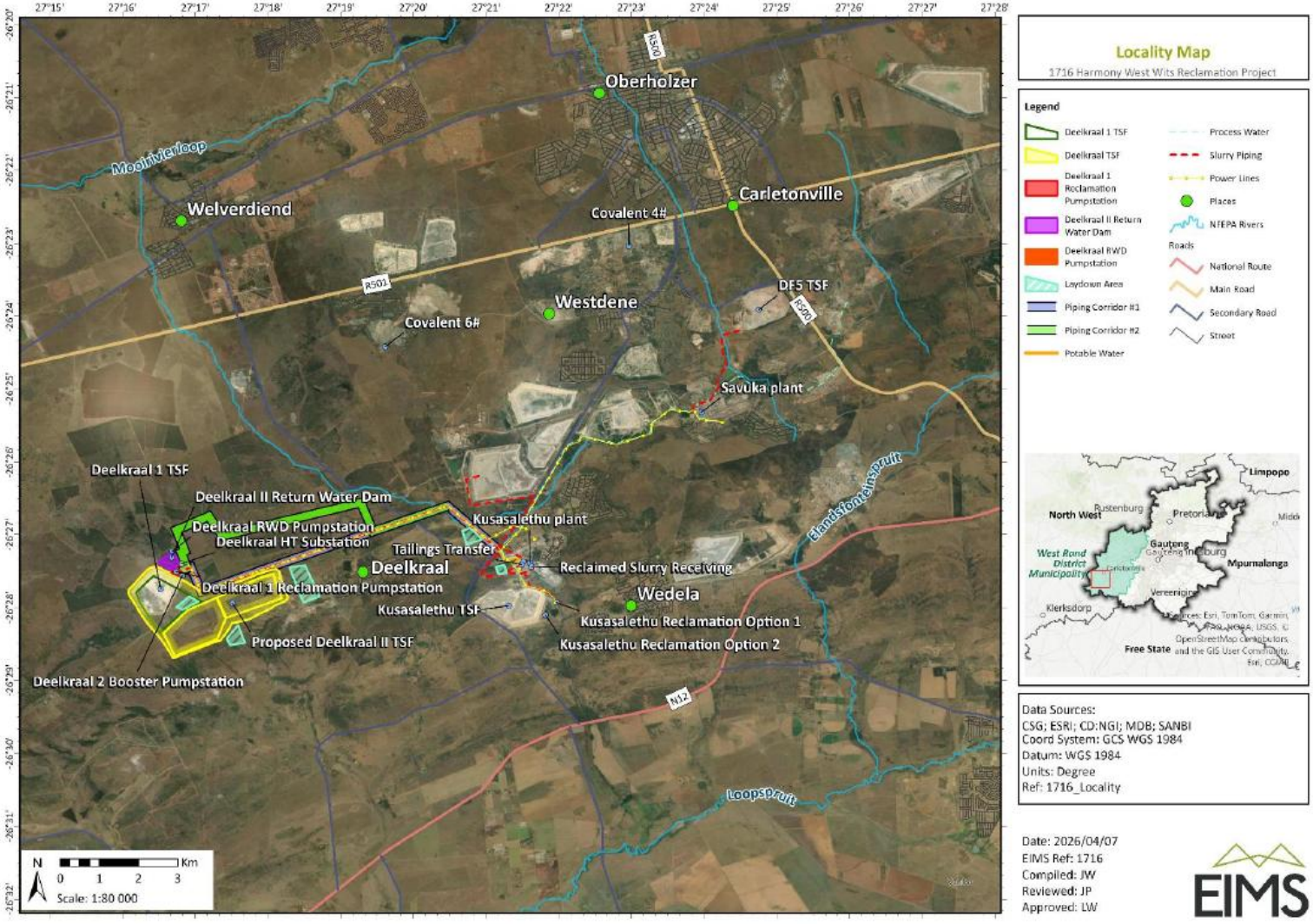


Figure 3.1 **Regional locality map showing the Project of Harmony in the Merafong City Local Municipality within the Southern District Municipality of the Northwest Province of South Africa (EIMS, 2026).**

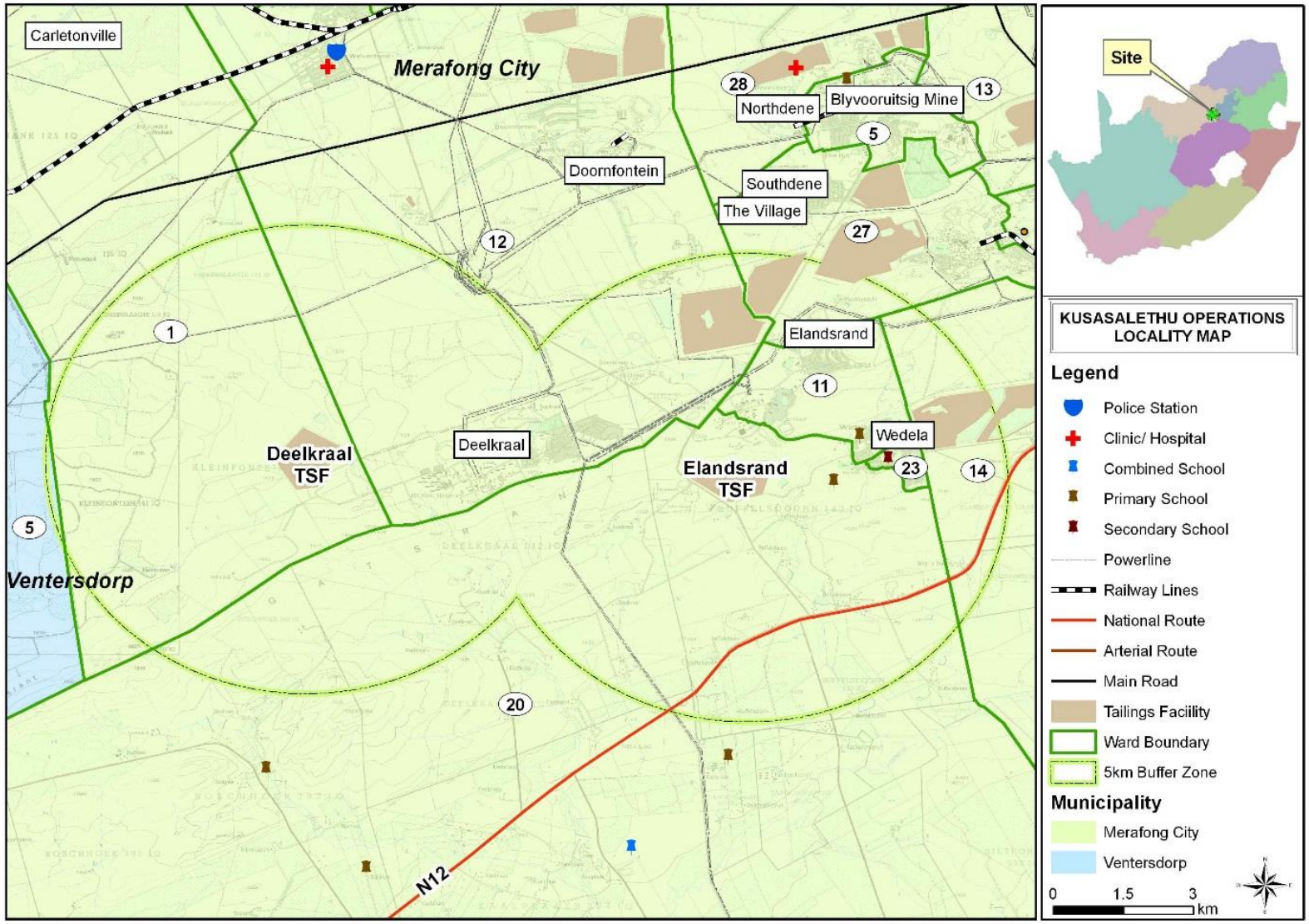


Figure 3.2 Location of the Kusasalethu Operations relative to surrounding communities (AquiSim, 2023).

3.3 Overview of the Kusasalethu Operations

3.3.1 General

The Project was briefly introduced in Section 1.1. Randfontein Estates Limited (a subsidiary of Harmony Gold Mining Company) requires additional deposition capacity to support operations in the West Wits region. The Project therefore proposes constructing the Deelkraal II Tailings Storage Facility (TSF) to meet future capacity needs. This TSF will receive residue from the Kusasalethu and Savuka plants and will also assist in returning process water to reclaim the existing Deelkraal 1 TSF and the Kusasalethu TSF for processing at the Kusasalethu plant. Presented here is a more detailed historical overview of the Kusasalethu Operations and the associated activities and surface infrastructure, based on AquiSim (2023).

3.3.2 Historical Perspective

The Kusasalethu Operations comprise two established gold mines: Deelkraal and Kusasalethu (formerly Elandsrand). The name of the Elandsrand (incorporating Deelkraal) was changed to Kusasalethu Operations in February 2010, meaning "*our future*" in Zulu (AquiSim, 2023).

The former Elandsrand gold mine was established by the Elandsrand Gold Mining Company Limited, which was incorporated in June 1974. The mine was established and brought into production faster than any other mine of similar depth in South Africa. The sinking of the twin vertical shafts at Elandsrand began in January 1975 and was completed in December 1978. By the time its two shafts had been sunk to their final depths, much of the station cutting, the excavation of pump chambers, the installation of pumps, and haulage development had already been completed. Elandsrand produced its first bar of gold in 1979, thereby officially entering production. Figure 3.3 is a schematic diagram of the shaft and mining layout (AquiSim, 2023).

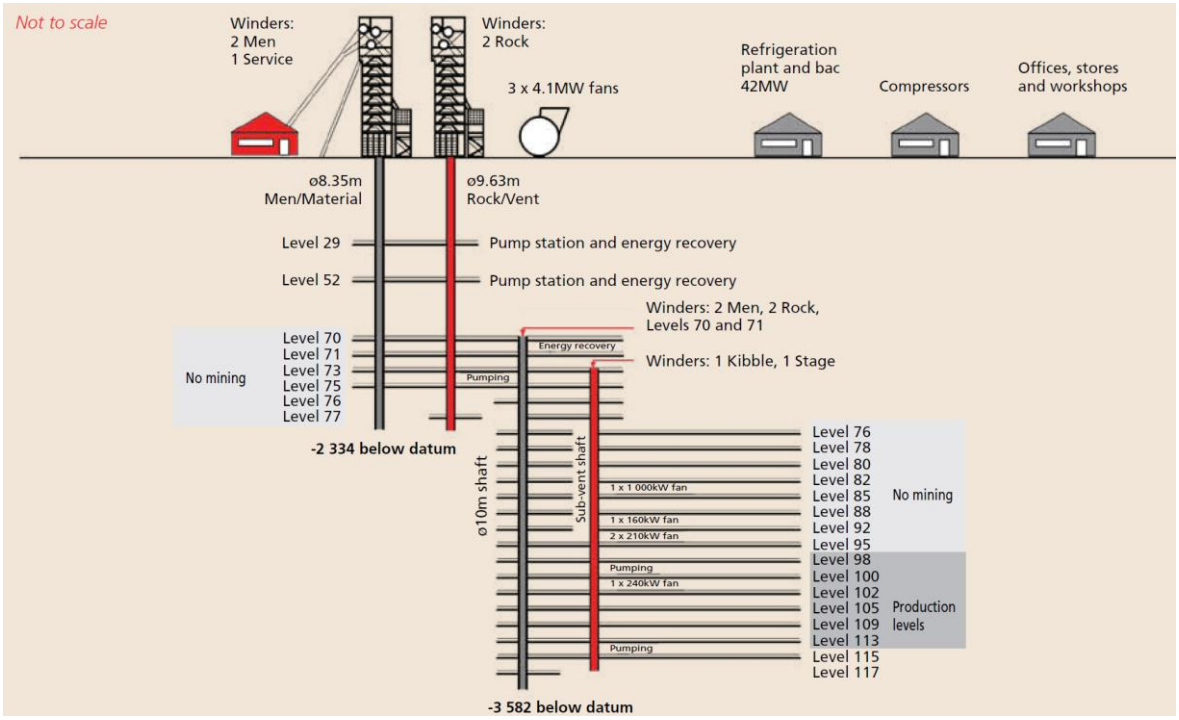


Figure 3.3 Schematic diagram of the Kusasalethu Operations shaft and mining layout (AquiSim, 2023).

The 10 m-diameter rock/ventilation shaft was initially sunk to 2,195 m, and the man/material shaft to 2,127 m. By June 1984, a 10 m-diameter sub-vertical rock/service shaft had been completed to a depth of 3,048 m, and a 7 m-diameter sub-vertical ventilation shaft had been completed to the same depth. Both shafts were deepened to a final depth below the surface of 3,318m and 3,388 m, respectively, as part of the deepening project to extract the higher-grade pay shoot towards the west of the mine. In December 2014, a decision was taken to suspend operations in the old portion of Kusasalethu and to restructure the mine. Subsequently, mining above the 98-level ceased.

The Deelkraal mine, located adjacent to the former Elandsrand mine, was purchased by Harmony from AngloGold Ashanti in 2001. Harmony has been mining and processing gold ore in Deelkraal until 2004, when the surface area of the Deelkraal mine was sold to Moira Mining. No surface activities currently take place at the former Deelkraal complex.

3.3.3 Mineral Deposit and the Mine Products

AquiSim (2023) states that Kusasalethu Operations produces gold and gold-bearing slag, with silver as a by-product. The Operations target the Ventersdorp Contact Reef (VCR) as the primary and only economically viable orebody. The VCR gold-bearing reefs, present in the deep conglomerates of the Witwatersrand Supergroup, lie on the unconformity that separates the Ventersdorp Lavas (Klipriviersberg Formation) from the underlying Witwatersrand Supergroup.

The Carbon Leader Reef (CLR) has been extensively mined at the former Elandsrand mine, whereas the former Deelkraal mine exploited only the VCR and Deelkraal Reefs.

3.3.4 Mining and Mineral Extraction Process

Figure 3.4 depicts the typical mining and extraction process utilised at gold mining and mineral processing operations (AquiSim, 2023). The mining method employed is underground sequential grid mining, with regional dip-stabilising pillars, backfill, and pre-conditioning to offset the effects of mining at this depth. Mining involves drilling holes into the ore body, filling them with explosives, and blasting the rock face or ‘stopes’ to break the ore into pieces that can be transported to the surface. It is conducted over five levels, from 98 to 113 (see Figure 3.3). Large geological structures are stabilised using clamping pillars. Ore mined is transported by rail-bound equipment to the shaft’s main ore pass system, where it gravity feeds to the 115 level. Ore is then hoisted via the sub-vertical shaft to above the 73 level, then to the surface. Given the depth of mining, the major engineering infrastructure required includes surface and underground refrigeration and cooling installations.

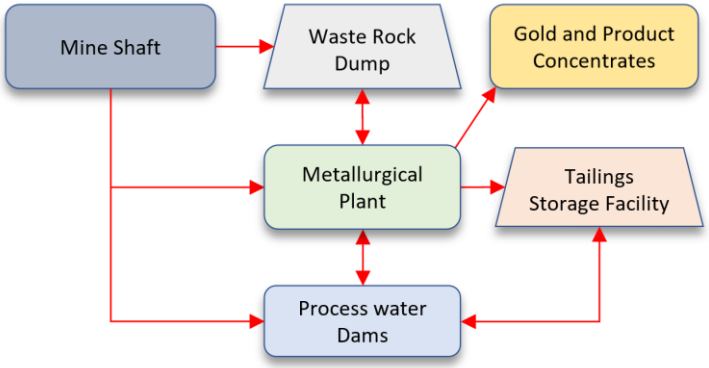


Figure 3.4 **Basic mining and metallurgical processes utilised at gold mining and mineral processing operations (AquiSim, 2023).**

Normally, the metallurgical gold processing plant receives the broken ore from underground via conveyor belts directly from the mine shaft. Rock that does not contain gold-bearing minerals, which is brought to the surface during shaft sinking or underground developments, is disposed of as waste rock at the waste rock dump. In addition, gold-bearing ore is stored in a stockpile near the processing plant, from where it is fed to run-of-mine mills. Water is utilised in the milling process, thus minimising dust release.

However, at the Kusasalethu Operations, the ore from underground is transferred to the Mponeng metallurgical plant for processing. Waste rock from Mponeng is transferred to the Kusasalethu metallurgical plant for processing. The waste rock is milled at the plant at a rate of 3 to 4 tonnes per day.

The slurry discharged from the milling section of the plant is density-classified using cyclones before thickening. The mill product is thickened through settling aided by the addition of flocculent chemicals. Underflow from the thickeners is leached using a standard cyanide leach process, which recovers about 90 % of the gold present in the feed material. The leach solution is separated from the leached solids using rotary drum filters and then transferred to the precipitation stage, where zinc/lead nitrate is added. The precipitated gold is recovered by filtration before calcining in a continuous calciner. No smelting is done on-site, and the gold doré is dispatched to Rand Refinery. Solids from the leaching process are pumped *via* pipelines to the Kusasalethu TSF (AquiSim, 2023).

3.4 Surface Infrastructure Relevant to the RPSA

3.4.1 General

Material (ore) brought to the surface from the underground workings contains naturally occurring radionuclides and is classified as NORM (per definition). However, members of the public may only be exposed to these materials once they reach the surface. The surface infrastructure through which radioactive materials may exit the underground workings or be distributed and deposited in the environment is thus of concern. The underground workings themselves, on the other hand, are not considered to contribute directly towards public radiation exposure and, therefore, are not considered further in this section.

3.4.2 Existing Infrastructure

Numerous historical surface infrastructure at the Kusasalethu Operations are also relevant to the RPSA (AquiSim, 2023). These include the downcast shafts and associated mining infrastructure, the metallurgical gold-processing plant, upcast ventilation shafts, TSFs, WRDs, pipelines, and water management infrastructure (e.g., process water dams and return water dams).

Table 3.1 summarises the historical infrastructure and features, while Figure 3.5 shows the locations of the relevant existing surface infrastructure. The features are separated into function-based categories and specified for each of the former Elandsrand and Deelkraal mines.

The remainder of the infrastructure, including materials management areas, offices, staff quarters, and training facilities, is not a potential source of public radiation exposure and therefore will not be further considered in the Project RPSA.



Figure 3.5 **Map showing the existing surface infrastructure and features that are of importance (AquiSim, 2023).**

Table 3.1 Summary of existing surface infrastructure and features (see Figure 3.5).

Area	Source Type	Latitude	Longitude	Status
Kusasalethu Operations (Former Elandsrand Mining Area)	Tailings Storage Facility	-26.4661	27.3566	Operational
	Waste Rock Dump	-26.4580	27.3630	Operational (reclamation by Stone and Allied)
	Return Water Dam	-26.4676	27.3650	No. 1 and No. 2 dams serve as return-water dams for the TSF complex.
	Processing Plant	-26.4574	27.3589	Operational, with a total capacity of approximately 220,000 tonnes/month.
	Unlined Trenches	Various		Transfers water between infrastructure
	Ventilation Shaft	-26.4545	27.3592	Operational, for rock and ventilation
	Downcast Shaft	-26.4534	27.3593	Operational, for workers and material
Former Deelkraal Mining Area	Tailings Storage Facility	-26.4631	27.2746	Dormant, currently maintained by a contractor to ensure physical integrity.
	Waste Rock Dump	-26.4616	27.3018	Reclaimed (only the footprint left)
	Return Water Dam	-26.4554	27.2770	Currently collects all surface-water runoff from the Deelkraal TSF.
	Processing Plant	-26.4644	27.3087	Demolished and removed
	Deelkraal Dam	-26.4571	27.3181	Non-operational
	Piet se Dam	-26.4534	27.3176	Non-operational
	Ventilation Shaft	-26.4674	27.3106	Operational, for ventilation
General	Pipelines	Various		Transfer water and tailings material between infrastructure

3.4.3 Proposed New Infrastructure

According to EIMS (2026), the West Wits Reclamation Concept Study explored ways to unlock the potential of recycling historic gold tailings using the existing Kusasalethu and Savuka process plants and infrastructure. Based on the project description, Harmony plans to remine the Deelkraal 1 TSF and the Kusasalethu TSF, amongst other potential future sources. These TSFs will be processed through the Kusasalethu Plant at 500,000 tpm. The planned Life of Mine (LoM) for the West Wits region exceed the available deposition capacity of the existing TSFs. Therefore, additional deposition capacity is required.

Harmony owns land next to the Deelkraal 1 TSF that can be utilised, such as for the proposed Deelkraal II TSF (see Figure 3.1). The combined layout of the Deelkraal 1 TSF and the surrounding virgin land will support the projected deposition rate and capacity needed for future reclamation activities. The new TSF is planned to cover about 430 hectares. In addition to the proposed construction of the Deelkraal II TSF, additional infrastructure is also proposed, as follows (EIMS, 2026):

- A new Return Water Dam in the vicinity of the Deelkraal II TSF.
- Upgrades to the existing Kusasalethu plant, including the new/upgrade of the gold and new uranium sections.
- Slurry pipelines:
  - Reclaimed Slurry from Deelkraal 1 to Kusasalethu (approximate length of 10.6 km[1]).
  - Kusasalethu Barren Tailings to Deelkraal II and booster pump station (approximate length of 10.2 km).
  - Reclaimed Slurry from Kusasalethu TSF to Kusasalethu Plant (approximate length of 2 km).
  - Slurry pipeline from Kusasalethu Plant to Savuka TSF (approximate length of 5 km).
  - Slurry pipeline from Savuka Plant to DF5 TSF (approximate length of 2.9 km).

[1] *Lengths of pipelines and powerlines provided are approximate and could change by 1 – 2 km depending on the routing alternative selected*

- Process Water Pipelines:
  - Process Water Feed from Kusasalethu Plant to Deelkraal Reclamation (approximate length of 9.54 km).
  - Return Water Feed to Kusasalethu Process Water Tank (approximate length of 9.58 km).
  - Driefontein DP2 Pump Station to North Boundary Dam (approximate length of 4.8 km).
  - DP2 feed to Tau Tona Reverse Osmosis Plant (approximate length of 0.1 km).
  - Nursery Pumpstation #3 to Kusasalethu Process Water Tank (approximate length of 9 km).
  - 2 Process Water pipelines from Kusasalethu Plant to Savuka White Tanks (approximate length of 8 km).
- Powerlines (all powerlines will be 22kV or lower):
  - Powerline from Kusasalethu Plant to the existing Deelkraal TSF (approximate length of 9.2 km).
  - Powerline from Kusasalethu Plant to the Kusasalethu TSF (approximate length of 1.8 km).
  - Powerline from Savuka shaft to Kusasalethu Plant (approximate length of 8.1 km).
- Potable Water pipeline from Rand Water supply point to the Deelkraal TSF (approximate length of 8.5 km).
- Deelkraal 1 TSF Reclamation Pump Station.
- Kusasalethu TSF Reclamation Pump Station.
- New Access Roads (2 x 3.5 m double road) adjacent to pipeline routes/OH lines and around Deelkraal II TSF (where no access road is already in place).
- Topsoil Stockpiles and overburden stockpiles.
- Ancillary construction infrastructure including workshops and laydown areas.

All pipelines listed above will be flanged steel pipelines installed above ground on precast concrete plinths, and two 3.5 m-wide access roads (double road) adjacent to the pipelines will be cleared/graded to provide access for construction, maintenance, and inspections (for areas where no access road is already in place). The pipeline diameters will be confirmed during the EIA phase once further design information becomes available (EIMS, 2026).

3.4.3.1 Tailings Storage Facility (TSF)

A Tailings Storage Facility (also known as mine dumps, slimes, tails, leach residue, or slickens) are the material left after the process of separating the valuable fraction from the uneconomic fraction of an orebody. Tailings are distinct from overburden or waste rock, which are the materials overlying an ore or mineral body that are displaced and brought to the surface during mining without being processed.

According to EIMS (2026), the construction phase of the Project will consist of site establishment, site clearance, excavation, topsoil stockpiling, layering and compacting, prior to deposition of tailings at the site. Details and locations of additional infrastructure, such as construction camps, access roads, temporary laydown areas, and associated infrastructure such as pump stations, will be presented in the EIA report.

The TSF will be constructed in three separate compartments as indicated in Figure 3.6, while Table 3.2 summarises the key parameters of the Deelkraal II TSF design.



Figure 3.6 Deelkraal II TSF compartments (EIMS, 2026).

Table 3.2 Deelkraal II Design Information (EIMS, 2026).

Design Aspect	Design Criteria
Deposition Method	Cyclone
Maximum final height (m)	65
Footprint Area (Ha)	430
Total Capacity (Mt)	Compartment 1: 80.85 Compartment 2: 53.9 Compartment 3: 57.6
Maximum Rate of Rise (m.year^{-1})	4.98
Total Deposition Period at 330,000 ton.mon^{-1} for Compartment 1	2028 – 2048 (20 years)
Total Deposition Period at 220,000 ton.mon^{-1} for Compartment 2	2028 – 2048 (20 years)
Total Deposition Period at 300,000 ton.mon^{-1} for Compartment 3	2036 – 2039 (4 years)
Total Deposition Period at 400,000 ton.mon^{-1} for Compartment 3	2040 – 2048 (9 years)

The following operational activity details are relevant to the current application (EIMS, 2026):

- An underdrainage system is provided beneath the RWD basin. Tailings material will be delivered to the site using new proposed slurry pipelines and deposition infrastructure.
- The TSF barrier system will be determined in consultation with the authorities and in compliance with relevant norms and standards for the determination of liner requirements, in accordance with NEM:WA (GN R. 636). The waste material solutes are classified as a Type 3 waste. This requires a Class C liner system. An inverted barrier system is recommended, as shown in Figure 3.7. It is a cost-effective alternative with superior performance compared to a Class C barrier.
- For water use, existing licensed water sources will be used and recirculated through the proposed Deelkraal II facility.

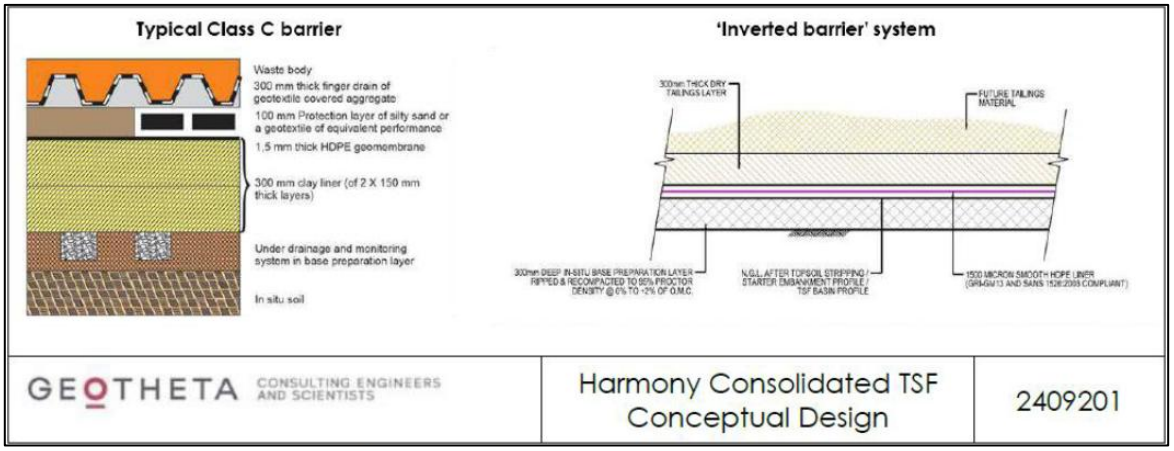


Figure 3.7 Comparison of typical Class C liner and inverted liner system (EIMS, 2026).

The construction timeline is estimated at 564 days (including tender evaluation periods). This extended construction period will require further rigorous planning for timelines and deposition access, which will need to be confirmed with the construction contractor(s). Construction is expected to commence in 2027, subject to all approvals being in place. A detailed closure plan will be developed during the life of the TSF. The objectives for the closure and rehabilitation of the TSF are to prevent pollution to the surrounding environment and ensure a stable facility is maintained.

3.5 Water Usage and Management

3.5.1 Water Use

The largest water use at the Project is for conveying materials during the metallurgical extraction and tailings disposal processes. Other uses for water at the Project include:

- Dust suppression during percussion drilling, watering down airways and as a wetting agent after blasting operations.
- In cooling systems, both in the condenser and evaporation circuits.
- Washing of underground mining equipment usually requires a combination of water and degreasing fluids. This water is contained within the process, and any residue is discharged into the metallurgical process for gold recovery.
- An independent drinking water supply is provided to the underground workforce, which ultimately flows into the main return water drain system.
- Some process water is lost through evaporation. In the underground workings, water vapour is entrained in the air vented through the main exhaust ventilation shafts and ultimately split to join the main drainage system or rejected to the atmosphere via the main ventilation fans on the surface.
- Ultimately, all the process water from the underground workings drains to the water treatment facilities at the bottom of each shaft. Here the water is stabilised and treated before being pumped to the surface where it is contained in holding dams and sent back underground for re-use via the refrigeration plant.

3.5.2 Wastewater and Polluted Water Management

Within the Kusasalethu Operations, there are separate reticulation systems for process water and clean water, as required under the National Water Act (Act No. 36 of 1998). Process water is reused as much as possible throughout mining and gold extraction, and the goal is zero effluent discharge to the environment. Process water is recirculated through a series of process water trenches and dams, designed to keep it on-site and separate from stormwater. No separation of stormwater into streams with high and low TDS concentrations is performed, and all stormwater is channelled to the return water system.

There are four points at which surface water originating from the Kusasalethu Operations can be released into the Environment. Table 3.3 summarises the surface water release points. The monitoring points and a discussion of the water monitoring data are provided in Section 3.6.3.3.

Table 3.3 Kusasalethu Operations surface water discharge points (AquiSim, 2023).

Release Point	Coordinates		Description
Golf Course Outlet	-26.4448°S	27.3595°E	Discharges stormwater runoff from the Kusasalethu shaft area, hostel and Elandsrand village
Deelkraal (Recreation) Dam and "Piet se Dam"	-26.4560°S	27.3184°E	The Deelkraal Dam collected stormwater runoff from the Deelkraal mine during its operational period. Piet se Dam is a pollution-control dam downslope from the Deelkraal Dam, which is in place in the event of the Deelkraal Dam overflowing.
Kusasalethu Return Water Dam	-26.4675°S	27.3654°E	This dam could overflow if the return water pumps fail or if there is excessive rain in the catchment area. It overflows to the Wedela Stream. No discharge from this dam has occurred in the last 18 months.
Deelkraal Sewage Outlet	-26.4742°S	27.2989°E	Deelkraal sewage works are owned and operated by a private contractor (Morgan Creek), which discharges treated sewage effluent from Deelkraal Village into the Loop Spruit, a tributary of the Mooi River. Water discharged here is not considered to contain radionuclides.

3.5.3 Groundwater Management

An updated hydrogeological study was conducted as part of the Project (MvB Consulting, 2026). The study confirms that the mine has an extensive groundwater monitoring network and that no additional boreholes were drilled during this investigation. The mine monitoring network at Deelkraal consists of 12 boreholes, of which 10 are shallow- and deep-borehole pairs drilled to monitor the shallow and deeper aquifer systems, respectively. At Kusasalethu, 9 mine-monitoring boreholes are available, including 1 shallow- and deep-borehole pair. The Deelkraal monitoring borehole locations are shown in Figure 3.8, with the Kusasalethu monitoring borehole locations depicted in Figure 3.9. A discussion of groundwater quality is provided in Section 3.6.6.

3.6 Description of the Baseline Environment

3.6.1 General

The purpose of this section is to provide a summary description of the environmental baseline conditions as observed near the Project. Within the conceptual assessment framework presented in Figure 1.5, the information presented here will inform understanding of the distribution of radioactivity released from the Project into the wider environment and the subsequent accumulation in environmental media.

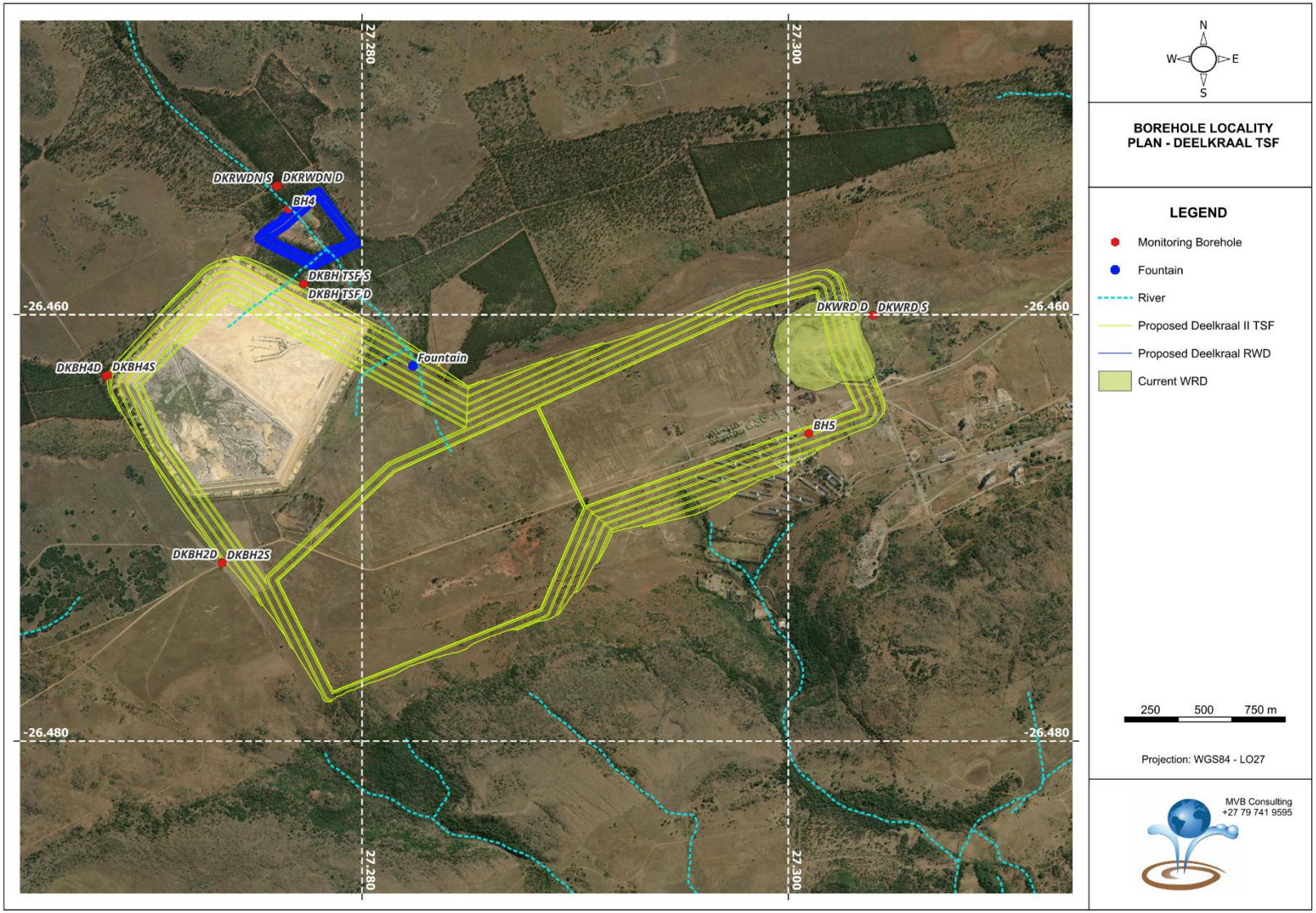


Figure 3.8 Deelkraal TSF monitoring borehole (MvB Consulting, 2026).

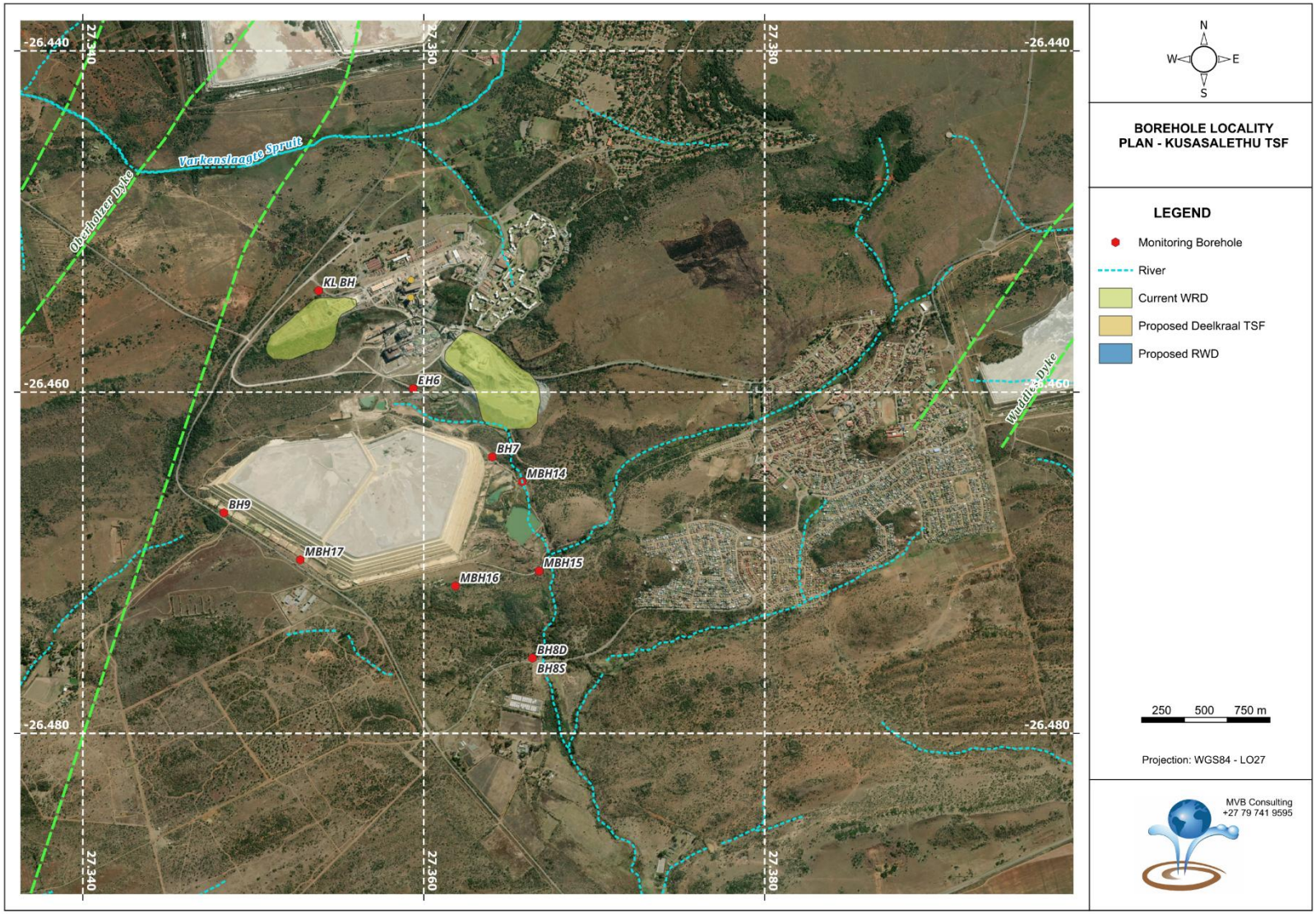


Figure 3.9 Kusasalethu Boreholes (MvB Consulting, 2026).

The environmental baseline conditions observed near the Project area are described in a series of specialist studies that serve as a basis and input into the radiological public safety and impact assessment process for the Project. The primary sources of information used for the description of the Project are as follows:

- A description of the topography and associated surface water drainage characteristics of the area, as provided in Hydrologic Consulting (2026) and MvB Consulting (2026).
- A description of the geology and associated hydrogeology as provided in MvB Consulting (2026).
- A description of the local meteorological conditions observed near the Project as provided in Hydrologic Consulting (2026) and Airshed (2026).
- A description of the socio-economic conditions observed near the Project as provided in Equispectives (2026).

Where necessary, information from these specialist study reports was supplemented with the information presented in the Scoping Report prepared by EIMS for the Project (EIMS, 2026), as well as the existing 2022 Kusasalethu RPSA (AquiSim, 2023).

3.6.2 Regional Topography

Figure 3.10 depicts the surface contours for the study area. Figure 3.10 also shows that the Gatsrand Ridge cuts across the operational area, with the former Deelkraal mine located north of the ridge (catchment C23E) and the Kusasalethu TSF and associated mining and mineral processing infrastructure located south of the ridge (catchment C23J).

The northern part of the operations (former Deelkraal mine) is located on a gently sloping broad valley running in a north-eastern to south-western direction, initially changing to the north in the north-eastern portion of the former Deelkraal mine area. The valley's north-eastern extreme forms a local catchment area, in which a small dam (Deelkraal RWD) has been constructed. The southern limit of the valley is the scarp face of the Gatsrand, along which the surface infrastructure of the former Deelkraal mine was located.

Ground elevations across the Project area range from approximately 1,500 mamsl to 1,711 mamsl, changing rapidly over short distances from around 1,600 mamsl at the top of the ridge to 1,560 mamsl at the Varkenslaagte Spruit (a tributary of the Wonderfontein Spruit) in the north and 1,420 mamsl in the Loop Spruit to the south (Hydrologic Consulting, 2026; MvB Consulting, 2026). Slopes across the site are predominantly below 10 %, although the areas occupied by the existing TSFs are more undulating, with some slopes between 10 % and 30 % (Hydrologic Consulting, 2026).

3.6.3 Hydrology

3.6.3.1 Surface Water Drainage

The Project area straddles the West Witwatersrand Ridge (Gatsrand), a local water divide that bisects the regional surface drainage; this divide is indicated as the light-coloured topographical high in Figure 3.11. The site falls primarily within quaternary catchments C23E and C23J, which form part of the Lower Vaal Water Management Area, with the associated area of hydrological relevance (approximately 80 km^2) extending into catchment C23G (Hydrologic Consulting, 2026).

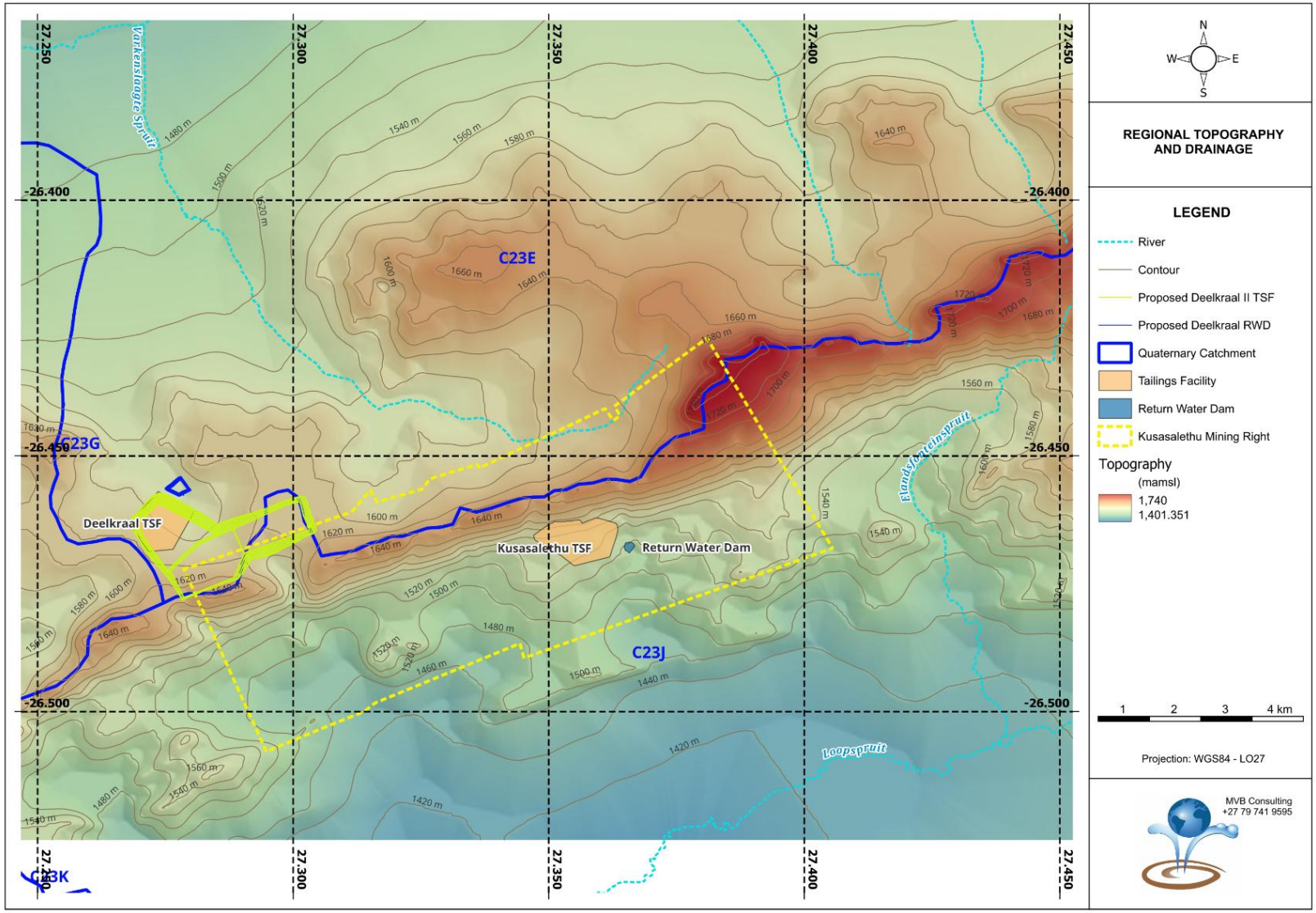


Figure 3.10 Regional topography and drainage of the Project area (MvB Consulting, 2026).

The catchment to the north of the divide, drained by the Wonderfontein Spruit and Mooirivierloop, is commonly referred to as the Mooi River Loop Catchment. The catchment to the south, drained by the Elandsfontein Spruit and Kraalkopspruit into the Loop Spruit, is the Loop Spruit Catchment. Both systems flow westward and eventually join the Mooi River, from where flow continues towards the Vaal River (Hydrologic Consulting, 2026; MvB Consulting, 2026).

Drainage from the decommissioned Deelkraal residue deposits is mainly to the north, within quaternary catchment C23E: the Varkenslaagte Spruit, a tributary of the Wonderfontein Spruit, flows westward along the northern boundary of the Harmony property, and the Wonderfontein Spruit in turn flows into the Mooi River and eventually the Vaal River. Drainage from the operational Kusasalethu residue deposits is mainly to the south, within quaternary catchment C23J, into the Loop Spruit, which flows westward and joins the Mooi River at Potchefstroom before continuing to the Vaal River (MvB Consulting, 2026).

Regarding Kusasalethu Operations' dirty water management, four surface-water drainage areas were delineated (AquiSim, 2023). These include (see Figure 3.11 for approximate directions of drainage from each area):

- Deelkraal TSF and Deelkraal Dam drainage areas;
- Golf Course drainage area;
- Sewage Plant drainage area; and
- Kusasalethu mine Drainage area.

On the northern side of the water divide, two watercourses originate from the mine property. The drainage areas from which the streams originate are the Deelkraal TSF, the Deelkraal Dam and the Golf Course areas. Historically, mine activities at the former Deelkraal mine have impacted these drainage areas.

In the Deelkraal TSF drainage area, a cut-off trench diverts the clean stormwater run-off around the TSF and into the stream, which drains the area to the north. Any seepage or excess stormwater run-off from the tailings is channelled to the Deelkraal RWD. No water potentially contaminated by the tailings leaves this drainage area. All spillage and stormwater runoff originating from the former Deelkraal mine, as well as from the WRD (Deelkraal Dam drainage area), are captured using open earth and concrete canals and pumped back to the plant for re-use.

Some excess seepage or stormwater that was not captured by the containment structures eventually flowed into the Deelkraal Dam. Since the decommissioning of the Deelkraal mine, no further contamination of run-off water has occurred. However, all seepage and stormwater run-off from the waste rock dump still flows into the Deelkraal Dam.

The capacity of the Deelkraal Dam is approximately 148,200 m^3. This dam overflows into the dam to the north of the Deelkraal Dam, namely Piet se Dam. Water from Piet se Dam overflows into a stream that joins an unnamed tributary of the Wonderfontein Spruit, which flows further downhill to the north. Water samples from the Deelkraal Dam are regularly collected for monitoring purposes.

Water from the northeastern part of the Kusasalethu Operations, which includes the Elandsrand residential area, also drains to the Wonderfontein Spruit tributary *via* the Golf Course Dam. This drainage area includes seepage and runoff from one of the Kusasalethu WRDs, as well as from the neighbouring Mponeng TSFs located north of the Elandsrand residential area. Surface water quality from this drainage area is monitored at a point downstream of the Golf Course Dam, known as the Golf Course outlet.

To the south, the Sewage Plant drainage area receives water released from the Deelkraal sewage plant. This plant treats sewage effluent from the Deelkraal hostel and the Schoonplaas residential area, located

at the former Deelkraal mine. To the southeast, the area surrounding the Kusasalethu Operations is drained by several small streams that converge into one stream near the Wedela residential area. This stream, commonly referred to as the Wedela Stream, is the third and last surface monitoring point and is considered representative of the surface water contamination from the mining operations.

3.6.3.2 Surface Water Use

According to AquiSim (2023), any water leaving the region on the north boundary enters a canal system that joins the Mooi River and eventually discharges into the Boskop Dam. Downstream of the Deelkraal Dam, the receiving environment consists mainly of natural vegetation for a radius of approximately 4 kilometres. Thereafter, cultivated lands occur until the receiving water body of the Wonderfontein Spruit is reached. Natural runoff mainly occurs during wet weather, and no direct abstraction of water from the stream occurs. Water from the south boundary flows through farms where it is used for irrigation. It enters a dam where it mixes with water from the Wedela sewerage plant. This water flows into the Loop Spruit, used for irrigation, and eventually flows into the Klipdrift Dam.

Table 3.4 summarises surface water use in the areas surrounding the Project. AquiSim (2023) indicates that surface water uses identified in the area include agricultural activities such as crop irrigation and livestock watering.

Table 3.4 Summary of the surface water use reported for the Kusasalethu Operations (AquiSim, 2023).

Surface Water Use	Description
Potable	Informal use only
Agricultural	Irrigation is seen as by far the most significant water use to the south of the operations.
Recreational use	Recreational fishing may take place in the Deelkraal Dam on a catch-and-release basis only.
Natural Environment	This is recognised as a legitimate use
Industrial	The importance of industrial use is reflected in potential industrial development supplied by the Vaal Dam

3.6.3.3 Surface Water Quality

Eleven surface water monitoring points were identified at the Kusasalethu Operations, from which samples are regularly collected to assess water quality in the area. Table 3.5 provides location coordinates for these monitoring points. Refer to Figure 3.5 and Figure 3.12 for an indication of the approximate location of the monitoring points.

The samples collected from the Golf Course drainage area all represent sources of surface water that eventually flow to the Wonderfontein Spruit tributary. Samples from the Mangaan Drive and the Golf Course dam were identified by AquiSim (2023) as the most impacted, with several water quality parameters indicating contamination exceeding national water quality limits. However, it is indicated that water leaving Kusasalethu Operations at the Golf Course outlet is of better quality than that recorded at the Golf Course Dam.

AquiSim (2023) reports that surface water quality in both the Deelkraal Dam and Piet se Dam appears to be good. However, water quality in the Deelkraal RWD is poorer, with elevated uranium concentrations. Treated sewage effluent released from the Deelkraal Sewage Works is of good quality and complies with national water quality guidelines. In the southeastern part of the operations, surface water from the Wedela Stream, Kusasalethu TSF and Loop Spruit Tributary all flow toward the Loop Spruit. The water quality at these points is typical of gold-mine process water, with elevated concentrations of soluble salt ions.

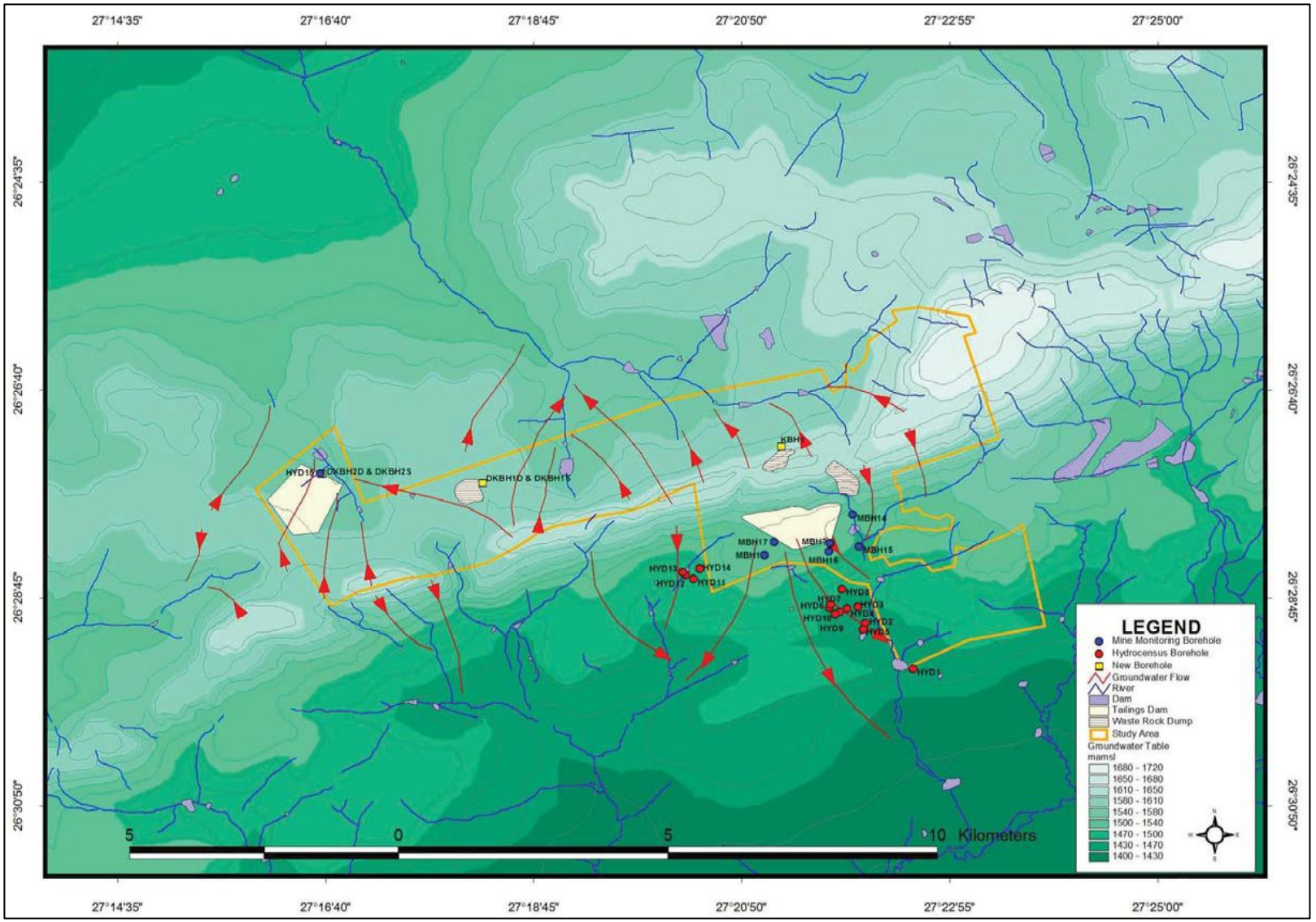


Figure 3.11 Surface water drainage in the Project Area (AquiSim, 2023).

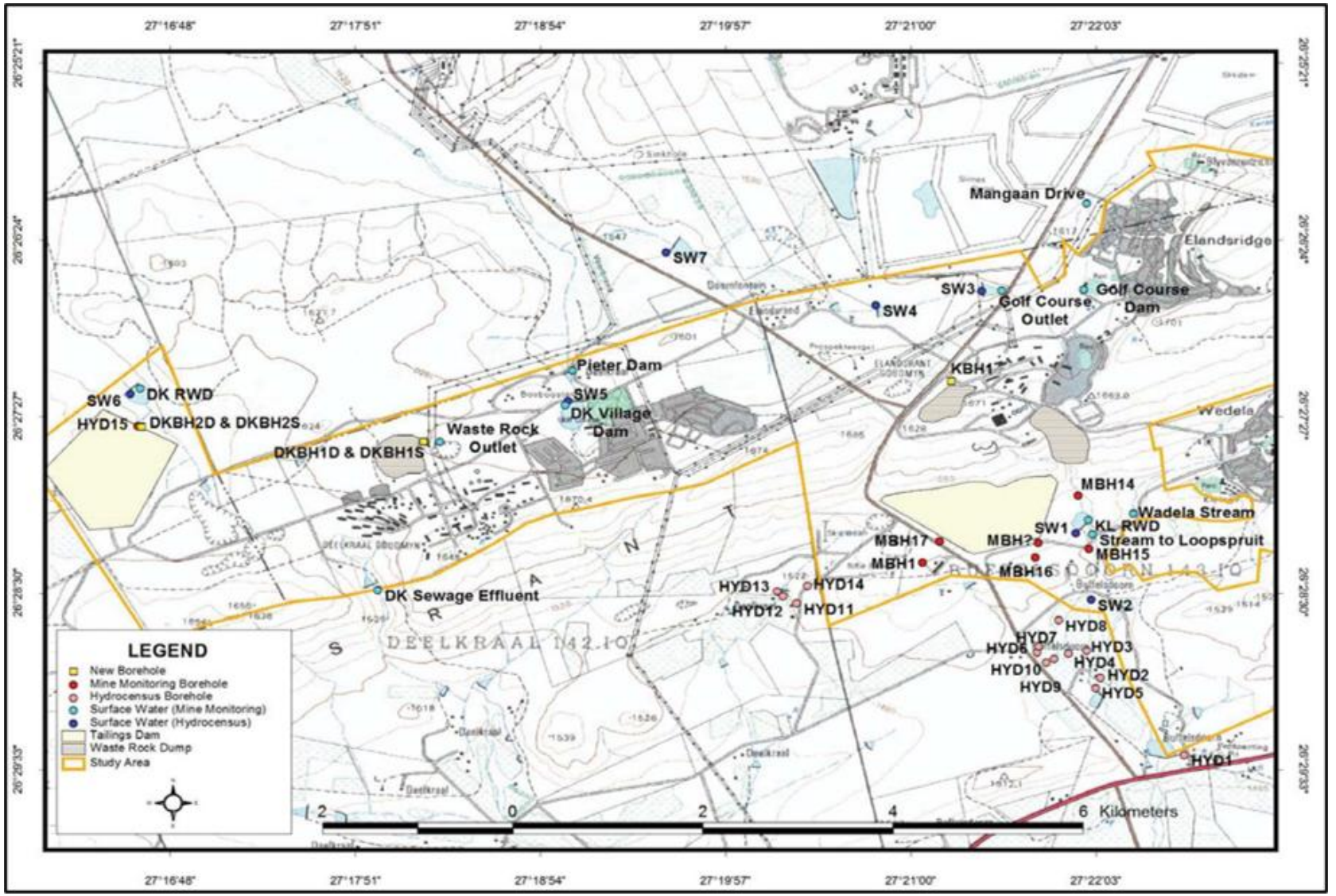


Figure 3.12 Surface and groundwater monitoring points at the Kusasalethu Operations (AquiSim, 2023).

Table 3.5 Surface water monitoring points at the Kusasalethu Operations (see Figure 3.12 for locations).

Monitoring Point	Coordinates	
Mangaan Drive	-26.4359°S	27.3672°E
Golf course Outlet	-26.4448°S	27.3595°E
Golf course Dam	-26.4449°S	27.3597°E
Deelkraal Dam	-26.4560°S	27.3184°E
Piet se Dam	-26.4532°S	27.3177°E
Waste Rock Outlet	-26.4603°S	27.3064°E
Deelkraal TSF Return Water Dam	-26.4548°S	27.2773°E
Deelkraal Sewage Outlet	-26.4742°S	27.2989°E
Wedela Stream	-26.4694°S	27.3677°E
Kusasalethu TSF Return Water Dam	-26.4675°S	27.3654°E
Loop Spruit Tributary	-26.4701°S	27.3674°E

One parameter of interest for radiological safety, measured at surface water monitoring locations, is the total chemical uranium concentration. Table 3.6 presents a summary of average minimum and maximum concentrations measured in surface water over the period from January 2011 to March 2017. The monitoring points presented include the eleven points listed in Table 3.5, as well as seven additional points for which monitoring data are available.

It must be noted that results were not available for all months for all the monitoring points. While some points were monitored monthly, others were sampled only for a limited period within the period. The calculated values in Table 3.6 may represent the entire 2011 to 2017 period or only a short period within it. Trend analysis for the results over the period is therefore not possible for most monitoring points.

Table 3.6 Summary of total uranium monitoring measurements (AquiSim, 2023).

Monitoring Point	Uranium concentration (ppb U)		
	Average	Minimum	Maximum
Mangaan Drive	5.2	BD	61.5
Golf Course Outlet	27.2	BD	222
Golf Course Dam	10.2	BD	101
DK Village	46.7	BD	173
Piet se Dam Outlet	39.1	BD	329.9
Waste Rock Dam	2.9	BD	9.2
DK RWD	801.3	17.0	11,459
Deelkraal Sewage Effluent	3.2	BD	13
Stream from Wedela	29.6	BD	2,032.6
KL RWD	24.9	BD	170
Stream to Loopspruit	3	BD	52.5
DK Slimes Dam	275.6	2.3	1,281
KL Underdrain	14.4	1.7	62
DK Underdrain	150.1	1.5	1,227.9
Vaarkenslaagte Dam	33.7	2.0	95
Kusasalethu Golf Course	61	1.3	418
KL Sewage Effluent	2.4	BD	46.8
KL RWD Seepage	14.8	BD	97
Loopspruit Downstream	3.4	BD	14

BD-Below detection limit. The limit varies for different datasets.

3.6.4 Geology

3.6.4.1 Regional Geology

The Project area is located in the Far West Rand Goldfield (West Wits Line), on the north-western rim of the geologically unique Witwatersrand Basin (see Figure 3.13). The Witwatersrand Basin remains the world's largest unmined gold source. Gold is produced from seven goldfields within the basin, mainly from conglomerate horizons of the Witwatersrand, Ventersdorp and Transvaal Supergroups. The gold mineralisation occurs within quartz pebble conglomerates, termed reefs, which are distributed across nine separate goldfields located along the eastern, northern and western margins of the basin (EIMS, 2026; MvB Consulting, 2026).

The Witwatersrand Supergroup is underlain by an Archaean (>3.1 Ga) granite-greenstone basement and the 3.086 to 3.074 Ma Dominion Group. It is unconformably overlain by rocks of the Ventersdorp (2.7 Ga), Transvaal (2.6 Ga) and Karoo (302 to 180 Ma) Supergroups. The Witwatersrand Supergroup can be further divided into two groups, the West Rand Group and the Central Rand Group. The Witwatersrand Basin comprises a 6 km-thick vertical section of argillaceous and arenaceous sedimentary rocks within the Kaapvaal Craton, extending laterally for 350 km east-northeast and 150 km south-southeast. Sedimentary rocks generally dip at shallow angles towards the basin centre, though locally this may vary. The basin sediments outcrop to the south of Johannesburg but, further west, are overlain by up to 4 km of Archaean, Proterozoic and Mesozoic volcanic and sedimentary rocks (AquiSim, 2023).

3.6.4.2 Local Geology

According to MvB Consulting (2026), the local geology consists largely of the clastic sediments and volcanic formations of the Transvaal Supergroup, which stretches from south of Johannesburg, beyond Carletonville to Orkney in the west. The Pretoria Group sediments (Rooihoogte and Timeball Hill Formations) form the prominent West Witwatersrand Ridge, south of the Malmani Subgroup dolomites of the Chuniespoort Group (Transvaal Supergroup), on which the Project is located. The dolomites of the Chuniespoort Group cover a large part of the study area with thicknesses ranging from 1,200 m to 1,450 m. The sedimentary rocks of the Pretoria Group overlie them.

The Kusasalethu Operations currently exploit the Ventersdorp Contact gold-bearing reef (VCR). The Carbon Leader Reef (CLR) was also exploited in the past. Both reefs occur in the deep conglomerates of the Witwatersrand Supergroup at the base of the Transvaal Supergroup. The VCR lies on the unconformity that separates the Ventersdorp Lavas (Klipriverberg Formation) from the underlying Witwatersrand Supergroup. The CLR is a thin quartz pebble conglomerate formed near the base of the Central Rand Group (the upper division of the Witwatersrand formations) and averages only 20 cm in thickness. The CLR is characterised by a carbon seam ranging from a few millimetres to a few centimetres, usually developed at or near its base. The reef may occasionally develop channels over 1 metre thick. At the former Deelkraal mine, the VCR and Deelkraal reefs were utilised. Figure 3.14 shows the geological formations underlying the Project.

Figure 3.14 indicates two large north-to-north-easterly striking faults that penetrate the underlying Ventersdorp and Witwatersrand Supergroups. The fault zones are reported to result from the Vredefort impact crater located to the south (AquiSim, 2023). Locally, some faults are filled by southwest-northeast-trending dykes of Pilanesberg age, which subdivide the near-surface dolomite formations into watertight groundwater compartments (MvB Consulting, 2026).

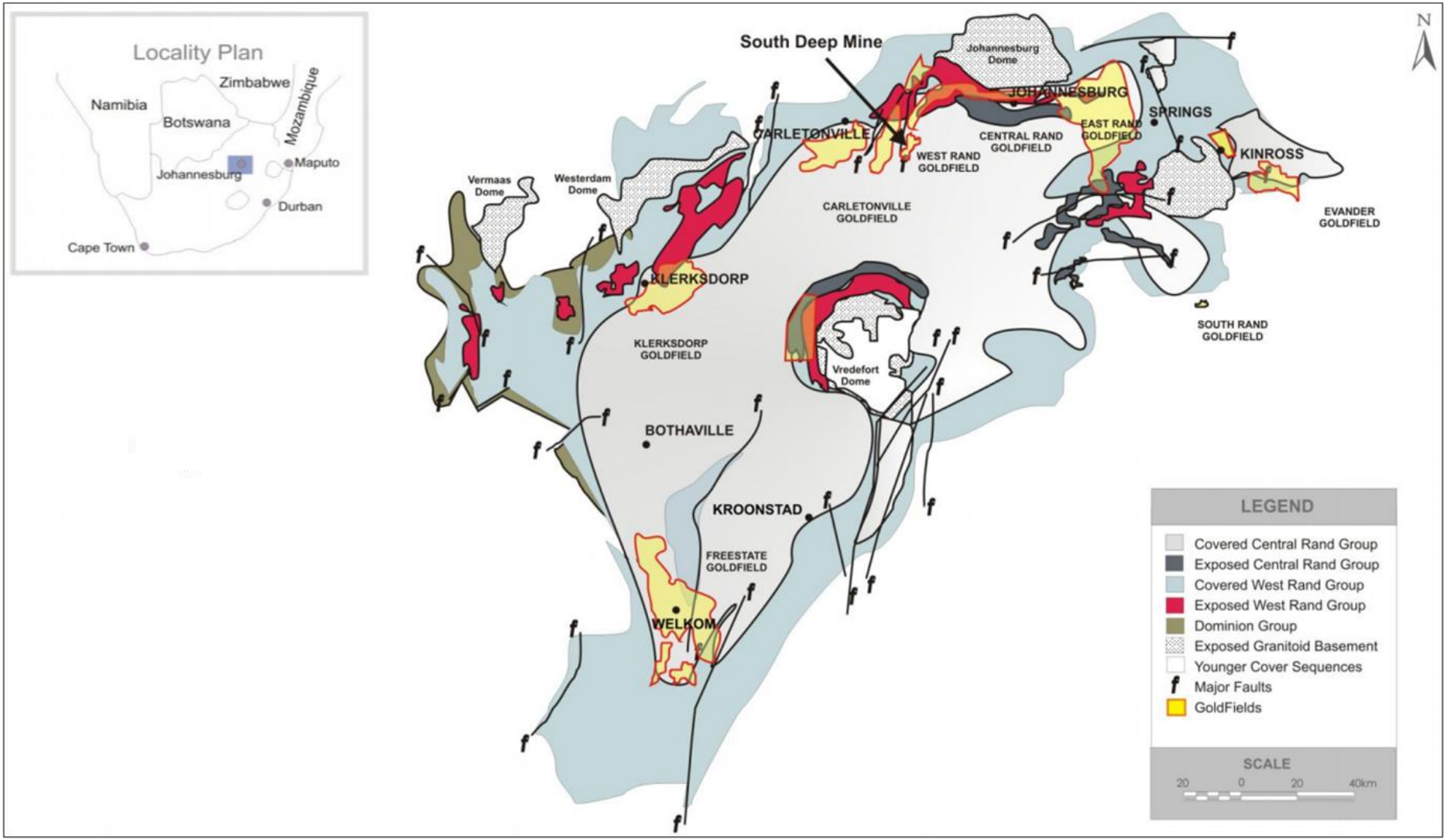


Figure 3.13 **Regional geology shows that the Project falls in the Far West Rand Goldfield (West Wits Line), on the north-western rim of the geologically unique Witwatersrand Basin (AquiSim, 2023).**

The dyke contact zones are characterised by fractures and transmissive zones which act as preferential pathways within the aquifer. Faults in the area form preferential pathways for groundwater movement and contaminant migration. Faults occur to the west as well as along the far north-eastern perimeter of the study area. Figure 3.14 shows one such watertight groundwater compartment (the Boskop–Turffontein dolomitic groundwater compartment), which is identified as a sensitive aquifer. The following geological conditions are encountered within the various sections of the Project area relevant to the assessment.

The Kusasalethu surface lease area is predominantly underlain by shale of the Timeball Hill Formation, comprising 150 m to 200 m of pink to purple shale overlain by quartzite that forms the linear ridges between the two TSFs. Further south, the Hekpoort and Strubenkop Formations consist predominantly of andesitic lava and ferruginous shale, respectively, the weathering of which produces grey to dark grey silty sand and clay. The Malmani dolomite outcrops approximately 500 m north of the Deelkraal TSF. It dips beneath these formations, occurring at depths of more than 100 m below the surface at the Deelkraal TSF and more than 400 m at the Kusasalethu TSF. Neither TSF is located on any of the mapped dykes (MvB Consulting, 2026).

3.6.5 Hydrogeology

3.6.5.1 General

Hydrogeological conditions are often closely linked to the geology of the area under investigation. The geological environment at the Project was briefly described in Section 3.6.4. The purpose of this section is to expand on this information and provide an overview of the hydrogeological conditions observed in the area. The groundwater pathway and associated hydrogeological conditions are often sensitive issues in radiological public safety assessments for mining and mineral processing facilities and are therefore given particular attention.

3.6.5.2 Aquifer Description

Three distinct aquifers occur in the vicinity of the Kusasalethu Operations, namely a Weathered Aquifer, a Fractured Aquifer and a Dolomitic Karst Aquifer (EIMS, 2026; MvB Consulting, 2026). The dolomitic aquifer occurs near the Deelkraal TSF and is unlikely to be affected by activities at Kusasalethu. The weathered and fractured aquifers underlie the entire Kusasalethu infrastructure, although the weathered aquifer is not consistently well developed. The Weathered Aquifer is shallow, semi-confined and restricted to the weathered shale and quartzite of the Witwatersrand rocks, bounded below by the impermeable quartzite and shale formations and above by the surface topography. Its water table broadly mimics topography and responds to seasonal and atmospheric variations, with the most consistent water-table depth at the fresh bedrock/weathering interface, and groundwater levels ranging from 0.5 m to 14 m below the surface.

According to MvB Consulting (2026), the deeper Fractured Aquifer occurs in the consolidated shale and quartzite, where fracture flow dominates. Jointing governs migration in the upper portion of the aquifer, while major faults and intrusions form significant conduits at depth. Depth to groundwater ranges from artesian to 38 m below the surface. The two aquifers are mostly hydraulically connected, although the Fractured Aquifer is confined by clay and shale layers that separate it from the other aquifer. The Dolomitic Karst Aquifer is developed in the Malmani dolomite to the north, where karstification along fault zones has produced fissures and cavities; it lies well below the two TSF sites and is not expected to be affected by the operations.

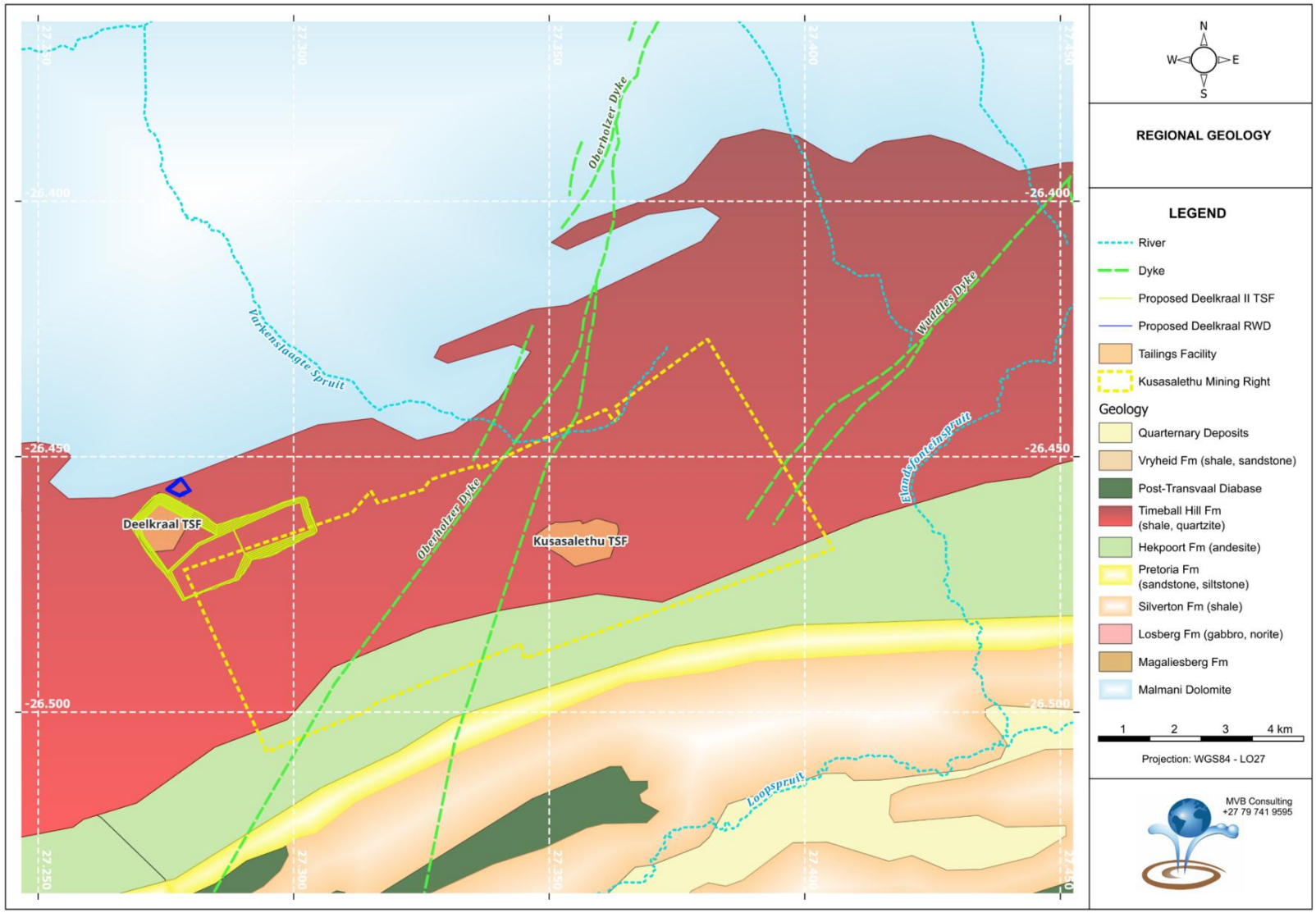


Figure 3.14 Surface geology underlying the Project (MvB Consulting, 2026).

Regional structures and low-permeability units further control groundwater movement. The dykes are largely impermeable and act as flow barriers, although their weathered contact zones can serve as conduits. The regional fault zones are permeable and form preferential pathways for groundwater flow and contaminant migration. The low-permeability shale and diabase formations act as aquitards, separating the deep and shallow aquifers, giving rise to semi-confined and artesian conditions and to localised springs within the study area. On this basis, the Fractured Aquifer is considered the most susceptible to impacts from the operations (MvB Consulting, 2026).

3.6.5.3 Aquifer Parameters and Classification

Table 3.7 summarises the average aquifer test parameters (MvB Consulting, 2026). Constant rate and recovery tests on the Kusasalethu and Deelkraal TSF monitoring boreholes give transmissivities of 0.740 $m^2.day^{-1}$ (weathered) and 1.058 $m^2.day^{-1}$ (fractured), with corresponding hydraulic conductivities of 0.085 $m.day^{-1}$ and 0.038 $m.day^{-1}$. These values indicate poorly developed aquifers that do not constitute economically exploitable hydrogeological units, although individual fractures may yield higher volumes, as observed in borehole DKBH1D.

Table 3.7 Summary of the aquifer parameters obtained from the aquifer test (MvB Consulting, 2026).

Borehole	Transmissivity ($m^2.day^{-1}$)			Hydraulic Conductivity ($m.day^{-1}$)		
	Constant Rate	Recovery	Average	Constant Rate	Recovery	Average
BH6	7.94E-01	3.46E-01	0.57	2.83E-02	1.24E-02	0.02
BH7	9.93E-01	1.99	1.49	4.15E-02	8.35E-02	0.06
BH8D	4.32E-01	1.33E-01	0.28	1.56E-02	4.78E-03	0.01
BH8S	1.77	5.63E-01	1.17	1.15E-01	3.67E-02	0.09
BH9	7.18E-01	5.02E-01	0.61	2.42E-02	1.69E-02	0.02
MBH14	9.93E-01	1.01E-01	0.55	5.02E-02	5.12E-03	0.03
KBH1	2.8E-01	1.49E-01	0.25	7.99E-03	4.24E-03	6.12E-03
DKBH 1S	Pumped Dry	1.79E-01	0.18	Pumped Dry	1.89E-02	0.02
DKBH 1D	4.42	2.95	3.69	1.47E-01	9.84E-02	0.12
DKBH 2S	Pumped Dry	8.71E-01	0.87	Pumped Dry	1.45E-01	0.15

Both the shallow weathered and the deeper fractured aquifers are classified as minor aquifer systems of very low yield, with low contamination vulnerability and a correspondingly low groundwater protection requirement under the National Aquifer Classification System (Parsons, 1995) and the associated Groundwater Quality Management index. Recharge, derived using the chloride mass balance method, is estimated at 3.7% of mean annual precipitation, or approximately 22 mm per annum (MvB Consulting, 2026).

3.6.5.4 Groundwater levels and Flow Regime

Groundwater gradients and flow directions were determined from the most recent water-level measurements in monitoring boreholes within and around the operations (MvB Consulting, 2026). Depth to groundwater ranges from 1.39 m to 23.92 m below the surface. Measured hydraulic head elevations correlate strongly with surface topography (R2 = 0.9783; Figure 3.15), indicating that groundwater flow mimics topography across the study area.

A regional groundwater gradient was accordingly generated by Bayesian interpolation of the measured groundwater levels and topography (MvB Consulting, 2026). Flow follows the topography away from the Gatsrand ridge in both directions: northwards near the Deelkraal TSF and waste rock area, and mainly south-west and south-east near the Kusasalethu operational features. Where groundwater levels are

shallow, some rivers are likely sustained by baseflow. The hydrogeological conceptual model is shown in Figure 3.16, and the interpolated regional groundwater gradient is shown in Figure 3.17 (MvB Consulting, 2026).

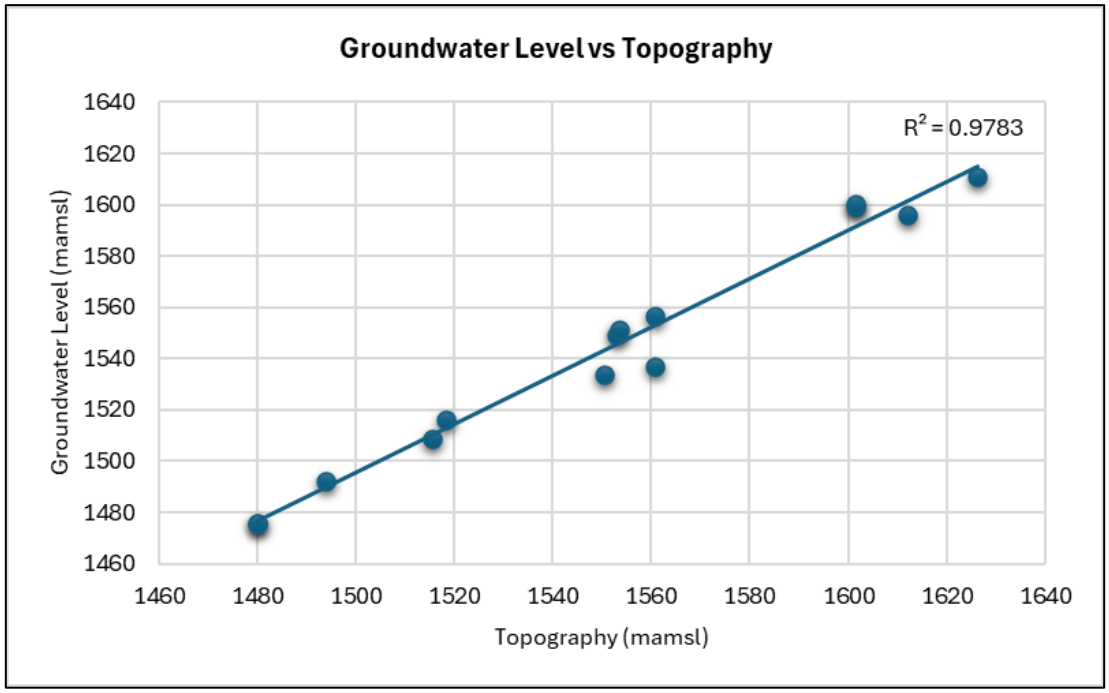


Figure 3.15 Relationship between the groundwater level elevation and the corresponding topography (MvB Consulting, 2026).

Note that the Dolomite Aquifer (Boskop-Turffontein Compartment) to the north of the Deelkraal Mine is very permeable and is dewatered due to deep underground gold mining. This dolomite compartment receives seepage from upstream minor fractured aquifers, which is pumped to the surface and used in mining operations. MvB Consulting (2026) confirms that no connectivity has been observed between the weathered/fractured aquifer system and the underlying dolomitic aquifer; even in compartments where the dolomite aquifer is dewatered, groundwater levels in the overlying weathered and fractured aquifers remain unaffected. The dolomite occurs at depths of more than 100 m below the surface beneath the Deelkraal TSF and more than 400 m beneath the Kusasalethu TSF, and is therefore not expected to be impacted by activities at these facilities.

3.6.5.5 Groundwater Use

Groundwater use in the area is limited. MvB Consulting (2026) confirms that Auctus Consulting undertook a hydrocensus in 2011 within a 2 km radius of the Kusasalethu and Deelkraal TSFs, with 10 of these boreholes remaining under bi-annual monitoring by the mine. A further hydrocensus in the Deelkraal area during 2026 investigated the area south of the proposed Deelkraal II TSF, where earlier surveys had identified no privately owned boreholes. Seven boreholes were recorded, three of them dry, together with a fountain east of the Deelkraal TSF at which remnants of illegal mining activity were observed (MvB Consulting, 2026).

The shallow weathered aquifer is poorly developed and locally dry, with the principal water-bearing horizons occurring in the deeper fractured system. Low aquifer yields and limited groundwater use in the vicinity of the TSFs together indicate a low overall vulnerability of the groundwater resource (MvB Consulting, 2026).

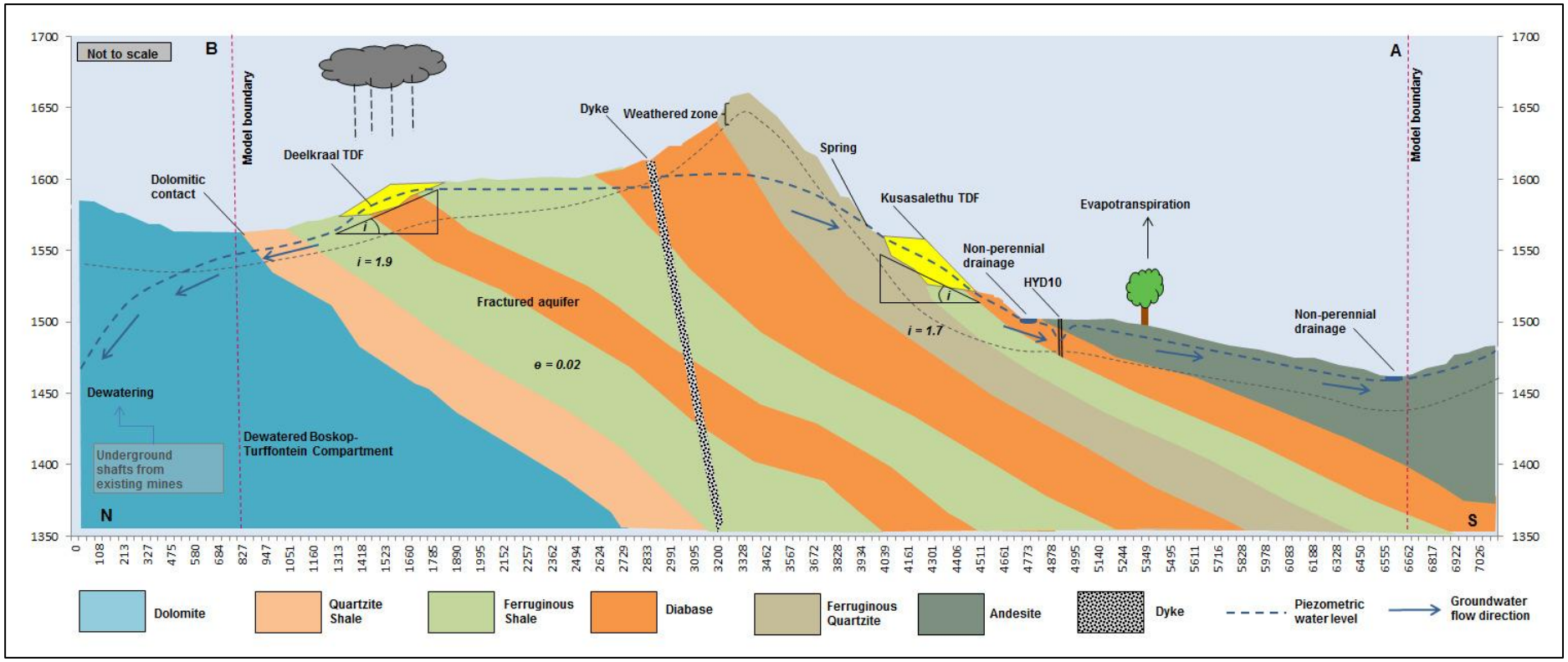


Figure 3.16 Conceptual hydrogeological model for the Project Area (MvB Consulting, 2026).

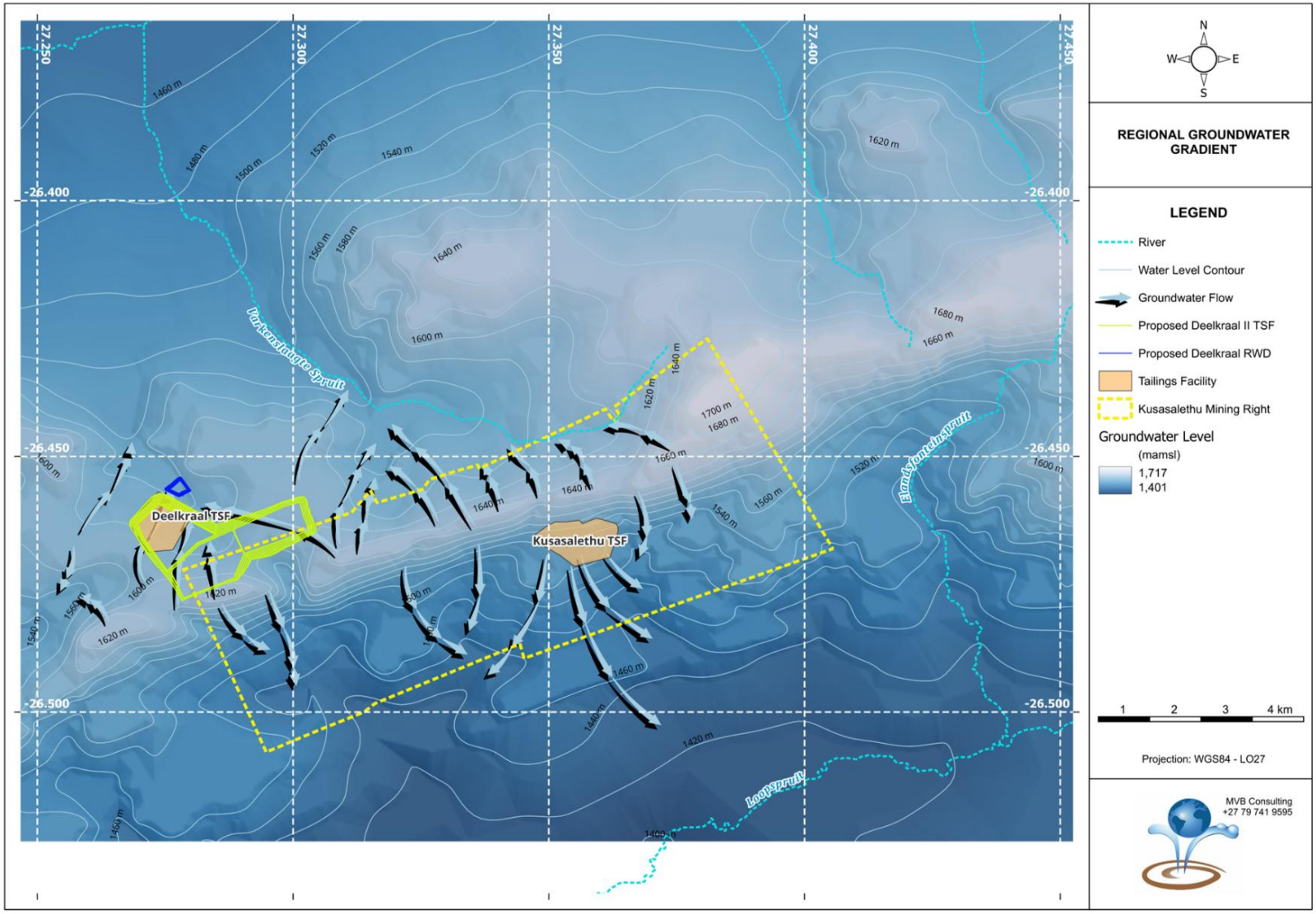


Figure 3.17 The groundwater levels and flow directions as determined by MvB Consulting (2026).

Reported uses of the private borehole water include crop irrigation, stock watering and domestic supply, including drinking water. No spring sources used for domestic supply or stock watering, near the Project area or further afield, were identified as likely to be affected by mining.

Deelkraal Mine is being dewatered via boreholes from the 98 Level into the workings to access ore reserves. The abstracted water enters the process water reticulation system, and the resulting excess is discharged at approximately 2.2 $ML.day^{-1}$ to prevent flooding of the shaft.

3.6.6 Groundwater Quality

3.6.6.1 Monitoring Data

As indicated in Section 3.5.3, groundwater monitoring at the Kusasalethu and Deelkraal Operations is focused on areas downgradient of the TSFs and WRDs. The purpose of most of these boreholes is to monitor quality in the shallow aquifer (Weathered Aquifer) and deep aquifer (Fractured Aquifer) separately. Figure 3.8 and Figure 3.9 indicate the approximate locations of all boreholes, while Table 3.8 lists the coordinates and identification numbers of the boreholes.

Table 3.8 Monitoring boreholes in the Project area (MvB Consulting, 2026).

Monitoring Point	Longitude	Latitude
Deelkraal TSF, RWD and WRD		
DKTSF(S)	27.27727	-26.4585
DKTSF(D)	27.27716	-26.4585
DKRWD(S)	27.27411	-26.4545
DKRWD(D)	27.27449	-26.4544
DKWRD(S)	27.30397	-26.46
DKWRD(D)	27.30398	-26.46
DK BH 2(S)	27.27344	-26.47165
DK BH 2(D)	27.27343	-26.47162
DK BH 4(S)	27.26806	-26.46283
DK BH 4(D)	27.26798	-26.46287
BH4	27.27662	-26.4552
BH5	27.30096	-26.46557
Kusasalethu TSF, RWD and WRD		
MBH14	27.36583	-26.4653
MBH15	27.36688	-26.4706
MBH16	27.36178	-26.4715
MBH17	27.35275	-26.4698
BH6	27.35982	-26.4599
BH7	27.36519	-26.4625
BH 8(S)	27.3664	-26.4756
BH 8(D)	27.3664	-26.4765
BH9	27.348	-26.467

Note: (S) denotes a shallow borehole monitoring the weathered aquifer
(D) denotes a deep borehole monitoring the fractured aquifer

Aquatico Scientific (Pty) Ltd routinely monitors the groundwater quality in the vicinity of the Kusasalethu and Deelkraal TSF's. From MvB Consulting (2026), monitoring coverage in the C23E catchment where Deelkraal is located is constrained by several boreholes that are either dry or inaccessible. The downgradient borehole pair DKBHTSF S/D confirms an impact from the TSF, with elevated EC, TDS, sulphate, calcium and magnesium, and very high manganese concentrations in the deep borehole. Both

boreholes are affected, but the deeper borehole is more severely impacted, indicating a hydraulic connection between the weathered and fractured formations in this area. Downgradient of the RWD, manganese is the only parameter elevated above the WUL limits. The WRD is monitored by a single borehole immediately downgradient of the facility, which shows no impacts or exceedances of the WUL limits. In physical terms, the monitoring localities range from neutral to alkaline (DKWRD S), and from non-saline (DKRWDN S, DKWRD S and KL BH) through very saline (DK BH TSF S) to extremely saline (DK BH TSF D).

Regarding the Kusasalethu Operations, groundwater is generally neutral in pH, except for MBH17, which is slightly acidic. Salinity increases along the flow path, from non-saline in the up-gradient borehole (KL BH) to very saline in the down-gradient boreholes (BH 8D). Elevated sulphate concentrations in all down-gradient boreholes indicate an impact from the TSF and the RWDs, with the greatest impact occurring to the south-west and south-east of the TSF, consistent with the prevailing groundwater flow directions. The highest sulphate concentration is recorded in BH 8D, the borehole furthest from the TSF, which cannot be explained by normal groundwater flow; transport along a geological structure or a spill in the adjacent stream are the two plausible mechanisms. Both the weathered and fractured aquifers are affected, but the deeper fractured aquifer is the more contaminated, suggesting migration along a geological structure rather than an origin in the stream (MvB Consulting, 2026).

Table 3.9 presents the total uranium concentrations that were elevated in selected boreholes (AquiSim, 2023). Based on the updated assessment from MvB Consulting (2026), uranium concentrations in all monitored boreholes in both areas were below the Water Use Licence and SANS 241 limit of 0.03 $mg.L^{-1}$.

Table 3.9 Summary of total uranium monitoring measurements (AquiSim, 2023).

Monitoring Point	Uranium concentration (ppb U)		
	Average	Minimum	Maximum
Waste rock Outlet B/H	18.63	BD	256
Anglo Store Borehole	1.54	BD	12.7
DK Borehole	0.97	BD	5.75
DK RWD	671.29	BD	3404
MBH 14	6.63	BD	276
MBH 15	5.75	BD	36
MBH 16	1.98	BD	34
MBH 17	0.33	BD	2.17
RV SHAFT	5.96	BD	51
KBH1	1.56	BD	15
DKBH2S	7.99	BD	168
DKBH2D	9.80	0.001	90.8
DKBH1S	2.06	0.004	5.45
DKBH1D	0.92	0.02	2.6

BD-Below detection limit. The limit varies for different datasets.

In addition to these monitoring boreholes, the Kusasalethu Operations annually monitor the quality of so-called “Hydrocensus Boreholes” located to the south and south-west of the Kusasalethu TSF. MvB Consulting (2026) found that ten of the original 14 hydrocensus boreholes remain under active monitoring (see Figure 3.18). Overall groundwater quality is good when benchmarked against SANS 241:2015 drinking water standards and is mostly compliant with the WUL limits. Elevated macro cation and anion concentrations in the hydrocensus boreholes are attributed either to aquifer heterogeneity and natural rock–water interaction, or to low-level mining impacts, given that the boreholes lie in the general downgradient flow direction.



Figure 3.18 Hydrocensus borehole locality – Kusasalethu area (MvB Consulting, 2026).

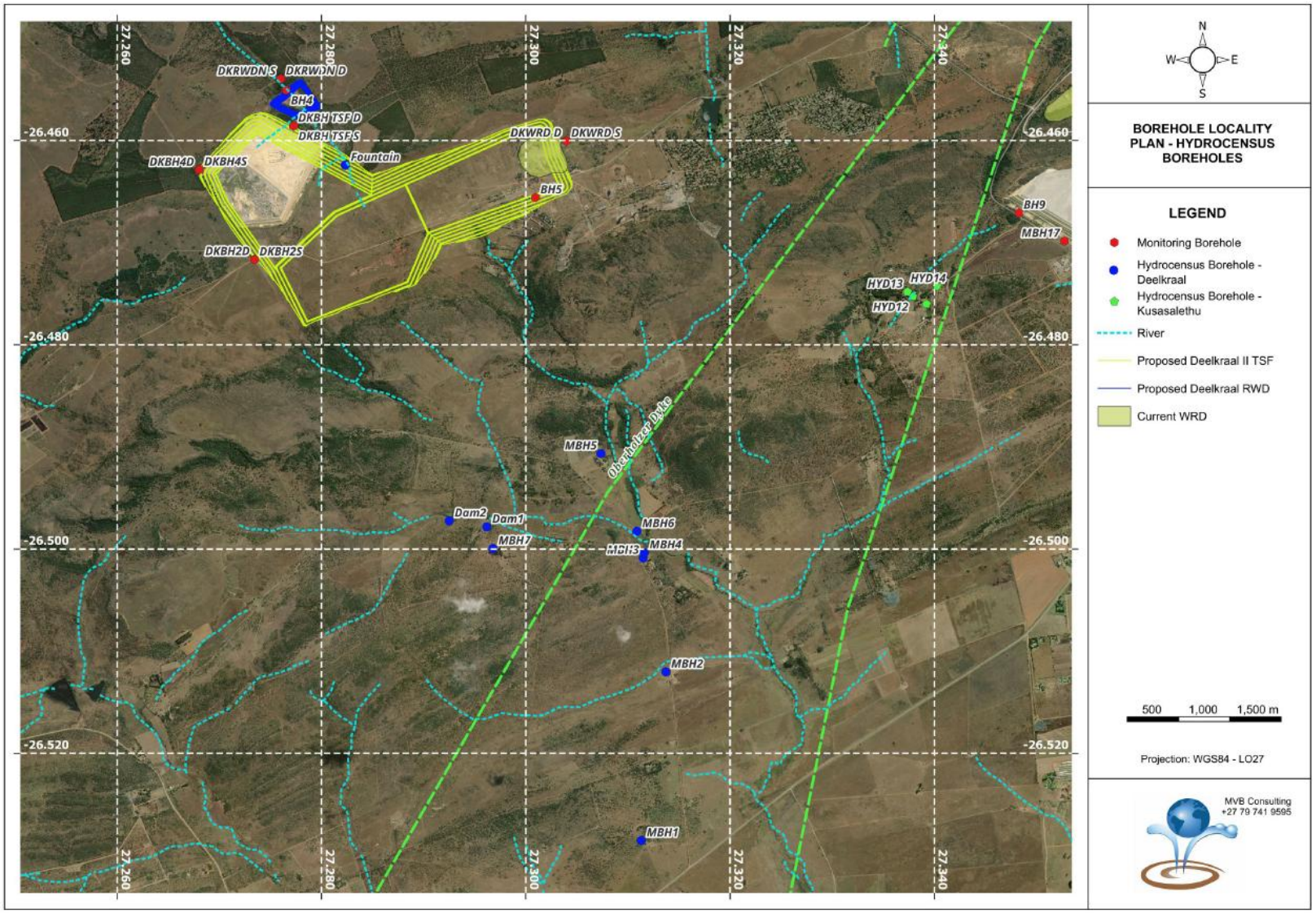


Figure 3.19 Hydrocensus borehole locality – Deelkraal area (MvB Consulting, 2026).

Magnesium dominates the cation content, while bicarbonate alkalinity, sulphate, and chloride dominate the anion content. The significant exception is bacteriological contamination: HYD2, HYD3, HYD11, HYD12, HYD13 and HYD14 returned unacceptably high levels, rendering the groundwater unsafe for human consumption.

From MvB Consulting (2026), a hydrocensus was undertaken in the Deelkraal area. Earlier hydrocensuses found no privately owned boreholes near the existing Deelkraal TSF, but the proposed new TSF prompted an extension of the survey southward. Seven boreholes were identified, three of which were dry (see Figure 3.19). A fountain east of the Deelkraal TSF was confirmed, with remnants of illegal mining evident at the site. Samples were taken from the boreholes, the fountain and one of the two dams down-gradient of the proposed TSF. Groundwater quality in the Deelkraal hydrocensus boreholes is good, with no SANS 241 exceedances, and the fountain water quality is very good and fully compliant. The only exceedances are for iron and manganese in the surface water of Dam 2 (MSW2).

3.6.6.2 Sources of Water Quality Impact

A geochemical investigation performed in 2012 for surface residue facilities (TSFs and WRDs) at both the Deelkraal and Kusasalethu areas (AquiSim, 2023) indicates that residue materials can release contaminants into the aquatic environment. The geochemical investigation evaluated the acid-producing and leaching characteristics of the residue materials.

Results of the evaluation indicate that Kusasalethu tailings material has a higher acid-forming potential than buffering capacity. The tailings material was indicated to have the potential to leach uranium, iron, aluminium, manganese and lead.

The waste rock was shown to have a lower average pyrite content than the tailings (around 0.3 wt %), and thus will not cause significant acid generation. Although the pyrite content of the waste rock is highly variable, the high dolomite content will counter any acid generation due to its buffering capacity. The waste rock has the potential to leach aluminium, iron and manganese (AquiSim, 2023).

3.6.6.3 Predicted Groundwater Quality Impacts

MvB Consulting (2026) developed an updated numerical groundwater flow and mass transport model for the study area using FEFLOW over a model domain of approximately 655 km^2. The steady-state flow model was calibrated against 41 boreholes, achieving a 93% correlation between observed and simulated groundwater levels. Sulphate (a conservative parameter associated with gold mining) was used as a tracer to simulate contaminant plume migration. The model simulated both the current impacts of the existing waste facilities and the predicted impacts over 50 years of reclaiming the Deelkraal and Kusasalethu TSFs and depositing the reworked tailings on the new Deelkraal II TSF.

As shown in Figure 3.20, the current sulphate plume at the Deelkraal TSF is migrating slowly towards the north, with a smaller plume developing towards the east; the plume is contained within the Harmony property and does not impact any downgradient receptors, and there is no significant impact from the Deelkraal WRD (MvB Consulting, 2026). At the Kusasalethu TSF, the current plume shown in Figure 3.21 is migrating primarily to the south, with a smaller plume towards the south-west; the plumes do not impact any private groundwater users but do affect two small streams. These plumes are expected to be limited to the weathered zone in the top 20 m. Because re-mining will remove the contaminant sources, the currently impacted aquifers beneath the TSFs are predicted to dissipate through natural attenuation, with plume concentrations largely reducing to below the Water Use Licence limits within 50 years (see Figure 3.23).

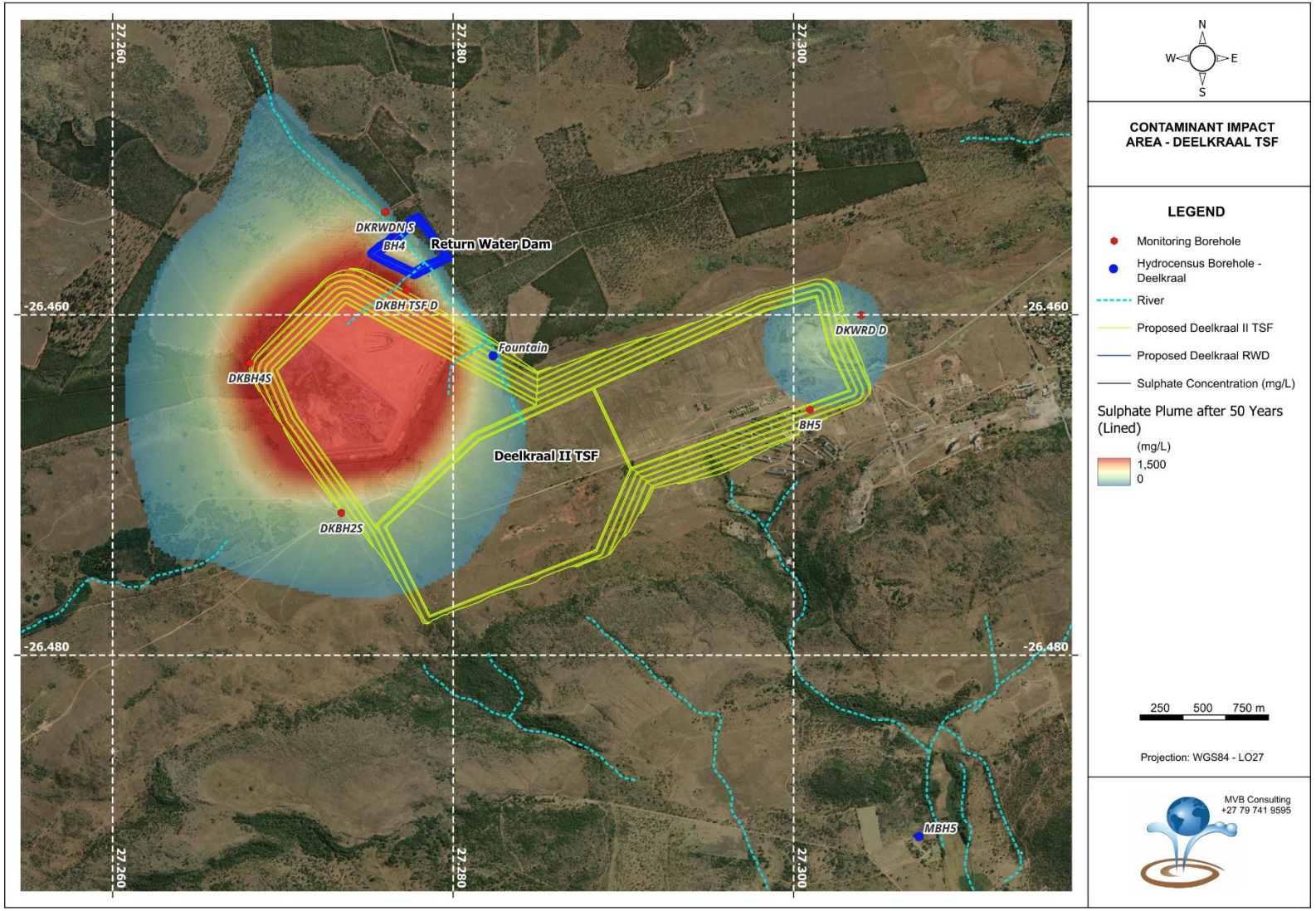


Figure 3.20 Current SO_4 plume at the Deelkraal mine (MvB Consulting, 2026).

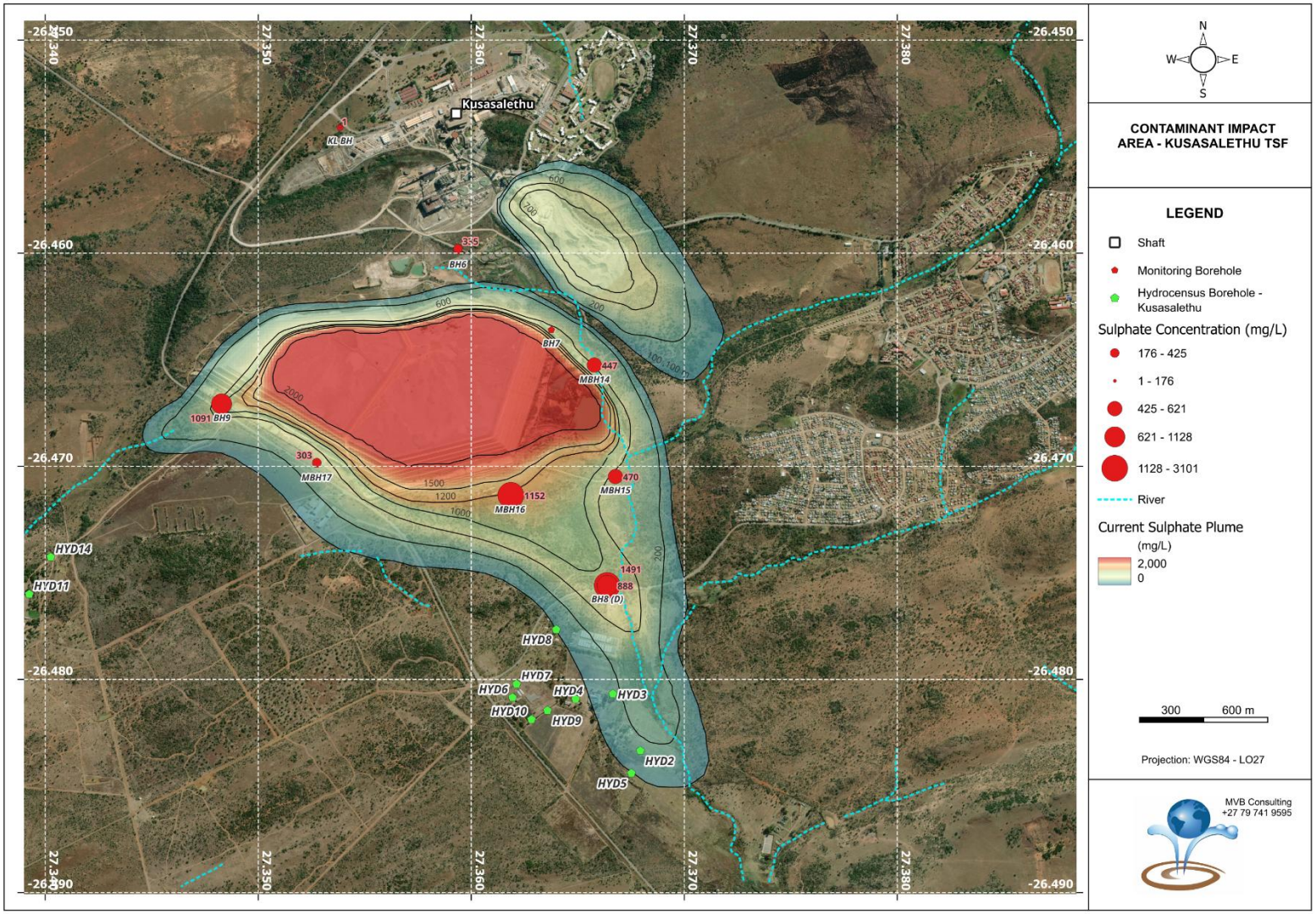


Figure 3.21 Current SO_4 plume at the Kusasalethu mine (MvB Consulting, 2026).

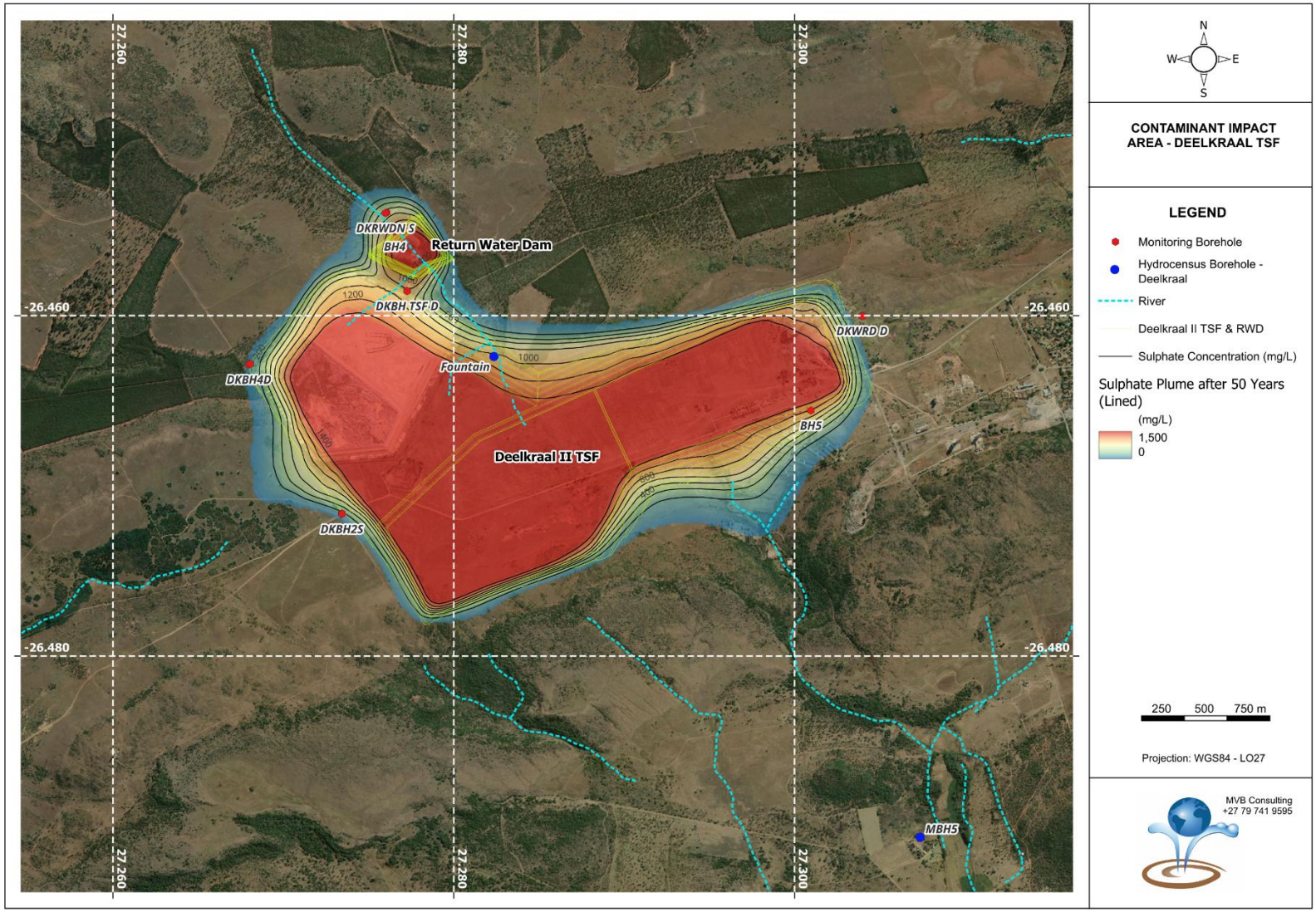


Figure 3.22 The simulated mitigated SO_4 plume after 50 years at the Deelkraal mine (MvB Consulting, 2026).

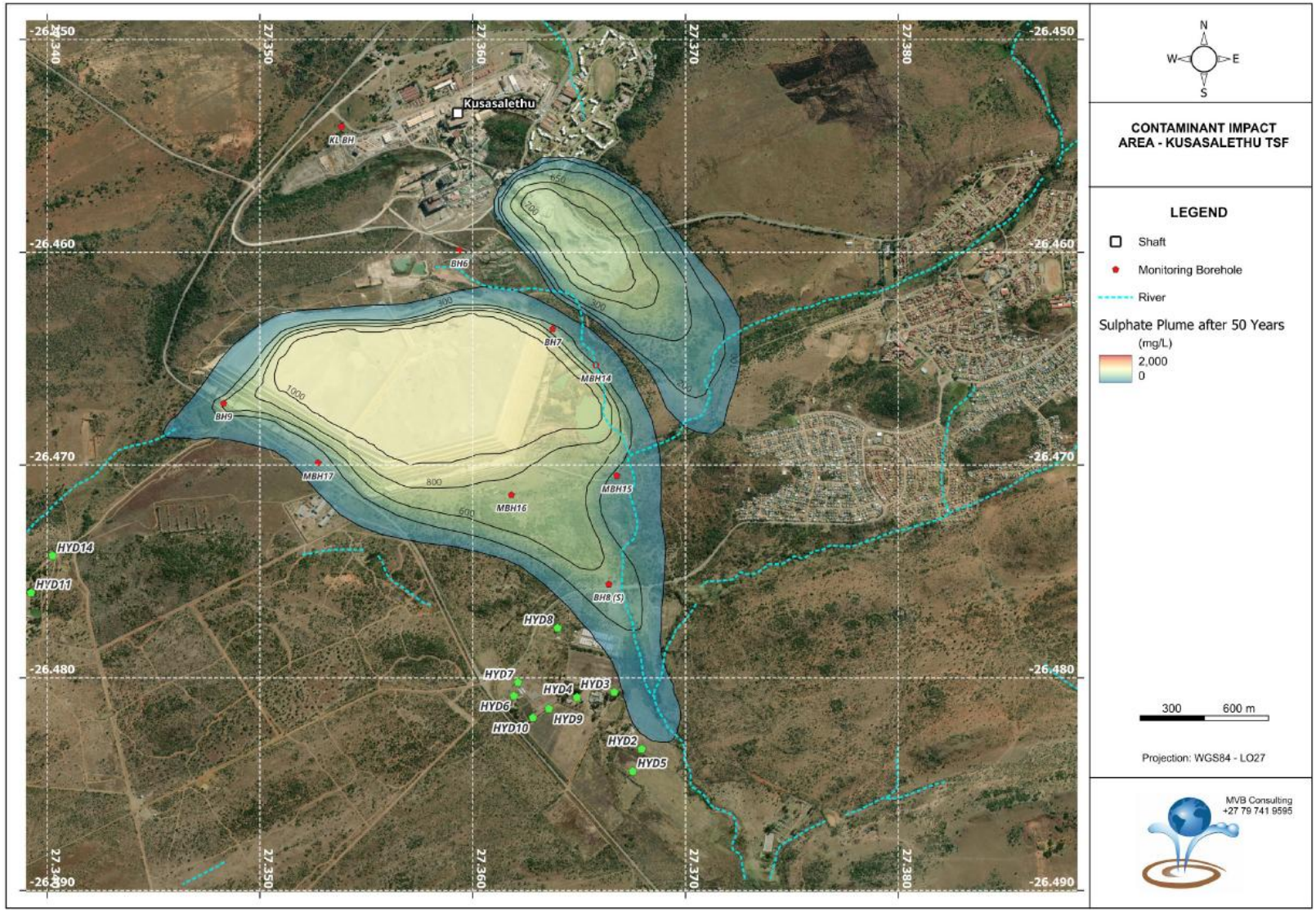


Figure 3.23 The simulated SO_4 plume after 50 years at the Kusasalethu mine (MvB Consulting, 2026).

Simulations of the proposed new Deelkraal II TSF and return water dam indicate that contamination is not expected to reach any downgradient receptors, whether the facilities are unlined or lined; a liner system further reduces the predicted seepage (see Figure 3.22).

MvB Consulting (2026) concludes that the re-mining of the Deelkraal and Kusasalethu TSFs will have a positive impact on the groundwater regime in the long term, and that the impact from the proposed new TSF and RWD is expected to be significantly less than that of the older facilities due to improved metallurgical processes and reduced sulphide content.

3.6.7 Meteorological Conditions

3.6.7.1 General

The regional climate is typical of the Southern African Highveld, with warm to hot summers and cold, dry winters, and is characterised by summer rainfall, with thunderstorms occurring frequently between October and April (EIMS, 2026; Hydrologic Consulting, 2026; MvB Consulting, 2026). A more detailed description of the prevailing meteorological conditions is provided in the Air Quality Impact report prepared by Airshed Planning Professionals (Airshed, 2026), which is based on three years' simulated WRF hourly meteorological data for a location at Savuka and Kusasulethu mines from 2022 to 2024.

3.6.7.2 Precipitation

The Project area falls within the summer rainfall region of South Africa, with rainfall occurring almost exclusively as showers and thunderstorms between October and April, peaking in January. Mean annual precipitation for the area is reported as between 565 mm and 697 mm (EIMS, 2026), while site-specific estimates adopt values of 640 mm, as shown in Table 3.10 (Hydrologic Consulting, 2026).

Table 3.10 Average monthly rainfall distribution (mm) (Hydrologic Consulting, 2026).

Month	Rainfall (mm)
January	113
February	91
March	83
April	44
May	19
June	7
July	6
August	8
September	19
October	59
November	88
December	101
Total	640

3.6.7.3 Ambient Temperature

Ambient air temperature is important for determining plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume can rise) and for developing the mixing depth and inversion layers. Daytime temperatures peak in the summer and decrease in the winter.

From Airshed (2026), monthly mean, maximum and minimum temperatures are given in Table 3.11. Diurnal temperature variability is presented in Figure 3.24. Temperatures ranged between -2°C and 35°C. The

highest temperature occurred in January and the lowest in July. During the day, temperatures rise to a maximum around 14:00. Ambient air temperature then decreases to a minimum around 06:00, i.e., just before sunrise.

Table 3.11 Monthly temperature summary (WRF data, January 2022 to December 2024) (Airshed, 2026).

Minimum, Average and Maximum Temperatures (°C)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Average	23	23	22	18	16	12	12	15	19	21	22	24
Hourly Maximum	33	35	33	29	27	23	23	28	30	33	34	34
Hourly Minimum	11	14	13	8	5	1	-2	1	4	3	7	13

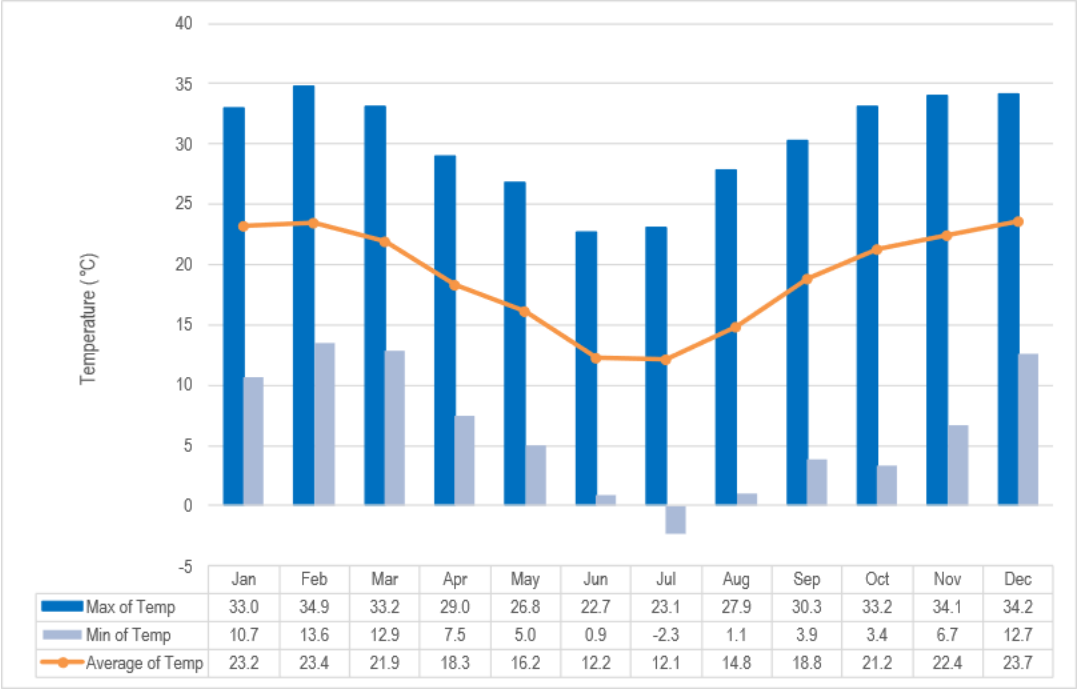


Figure 3.24 Diurnal monthly temperature trends (WRF data, January 2022 to December 2024) (Airshed, 2026).

3.6.7.4 Wind Speed

Airshed (2026) presents information on wind speed and direction. The measurements are summarised in wind roses (see Figure 3.25). Wind roses are graphical representations of measured wind speed and direction, each comprising 16 spokes that indicate the directions from which winds blew during a specific period. The colours used in the wind roses below correspond to different wind speed categories. The dotted circles indicate the frequency of wind speed and direction categories. The frequency with which calms occurred, i.e., periods during which the wind speed was below 1 $m.s^{-1}$ are also indicated.

Figure 3.25 shows the period wind field and diurnal variability in the wind field measured for the period January 2022 to December 2024. Figure 3.26 summarises the seasonal variation in the wind field.

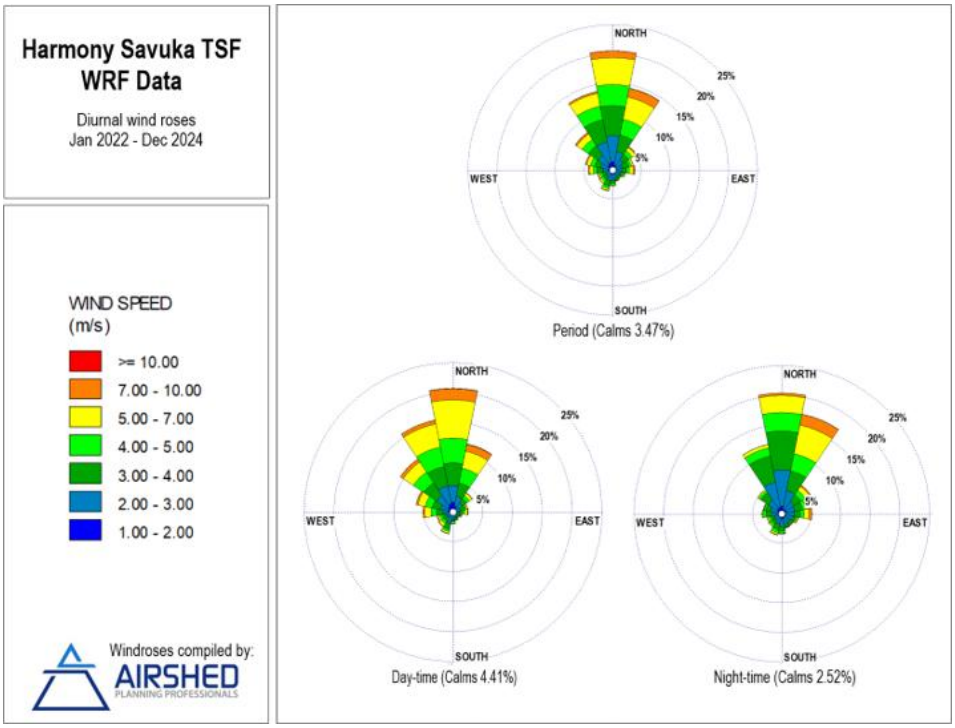


Figure 3.25 Period, day and night-time wind roses (WRF data, January 2022 to December 2024) (Airshed, 2026).

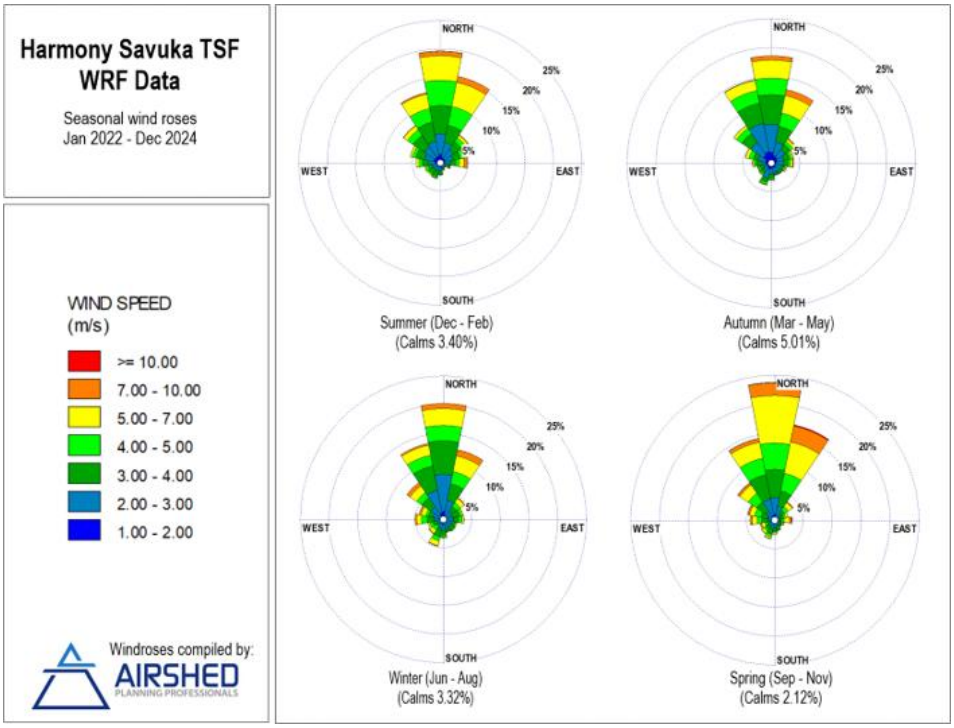


Figure 3.26 Seasonal wind roses (WRF data, January 2022 to December 2024) (Airshed, 2026).

The northerly winds prevail both day and night. The strongest winds (>6 m/s) occurred mostly from the north-northeasterly sector. Calm conditions occurred 3.5% of the time, with an average wind speed of 3.63 m/s over the period. Both daytime and nighttime show dominant northerly wind fields, with calm conditions at 4.4% during the day and 2.52% during the night. The dominant northerly winds prevail throughout the seasons, with wind speeds increasing during the spring months.

3.6.7.5 Ambient Air Quality

Ambient airborne dust concentrations (PM10) were monitored for a brief period (December 2014 to March 2015) at the Kusasalethu Operations. The results of this monitoring campaign (summarised in Figure 3.27) indicate that daily PM_{10} concentrations were below the South African National Ambient Air Quality (NAAQ) limit of 75 µg.m^{-3}, except for one measurement (89 µg.m^{-3}) in December 2014 2015 (AquiSim, 2023).

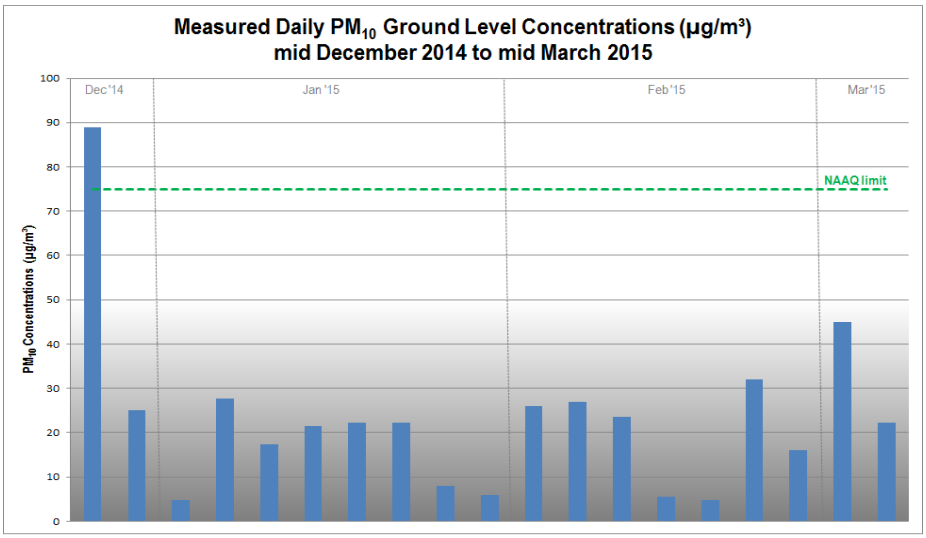


Figure 3.27 Daily PM_{10} concentrations measured at the Kusasalethu Operations from mid-December 2014 to mid-March 2015 (AquiSim, 2023).

The dust-fall monitoring network at the Kusasalethu Operations originally consisted of seven single buckets located in and around the operational areas. In December 2014, four additional dustfall buckets were added to the existing network, bringing the total to 11 monitoring points (AquiSim, 2023). The more recent report from Airshed (2026) states that dustfall sampling has been undertaken around the Kusasalethu operations since January 2019 by Aquatico Scientific, and that the network comprises 7 single Dustfall Monitoring Units (DMUs) in accordance with ASTM D1739 (1970). Five (5) of these DMUs are screened against the NDCR non-residential limit of 1,200 mg.m^{-2}.day^{-1}, with the remaining two (2) units regarded as residential (screened against the NDCR residential limit of 600 m^{-2}.day^{-1}). Coordinates for the original and newly added buckets are listed in Table 3.12 and indicated in Figure 3.30.

Table 3.12 Site description and location of Kusasalethu Dustfall Monitoring Units (DMU) (Airshed, 2026).

Mine	DMU	Longitude	Latitude	Classification	Status 2025
Harmony – Kusasalethu Mine	DK1 – Deelkraal Dust Bucket 1	27.29529	-26.4662	Non-residential	Active
	DK2 – Deelkraal Dust Bucket 2	27.29628	-26.47259	Non-residential	Active
	DK6 - Deelkraal Dust Bucket 6	27.3695	-26.43636	Residential	Active
	ER3 – Elandsrand Dust bucket 3	27.35774	-26.45294	Non-residential	Active
	ER4 - Elandsrand Dust bucket 4	27.36715	-26.46905	Non-residential	Active
	ER5 - Elandsrand Dust bucket 5	27.35284	-26.47134	Non-residential	Active
	ER7 - Elandsrand Dust bucket 7 (ER Village Dust Station)	27.37885	-26.43591	Residential	Active

Airshed (2026) report that during the five and a half years (January 2020 to July 2025) of dustfall monitoring for both the residential and non-residential locations, the dustfall rates were below the respective NDCRs, with one exceedance of the residential limit recorded at DK6 in November 2020 (see Figure 3.28).

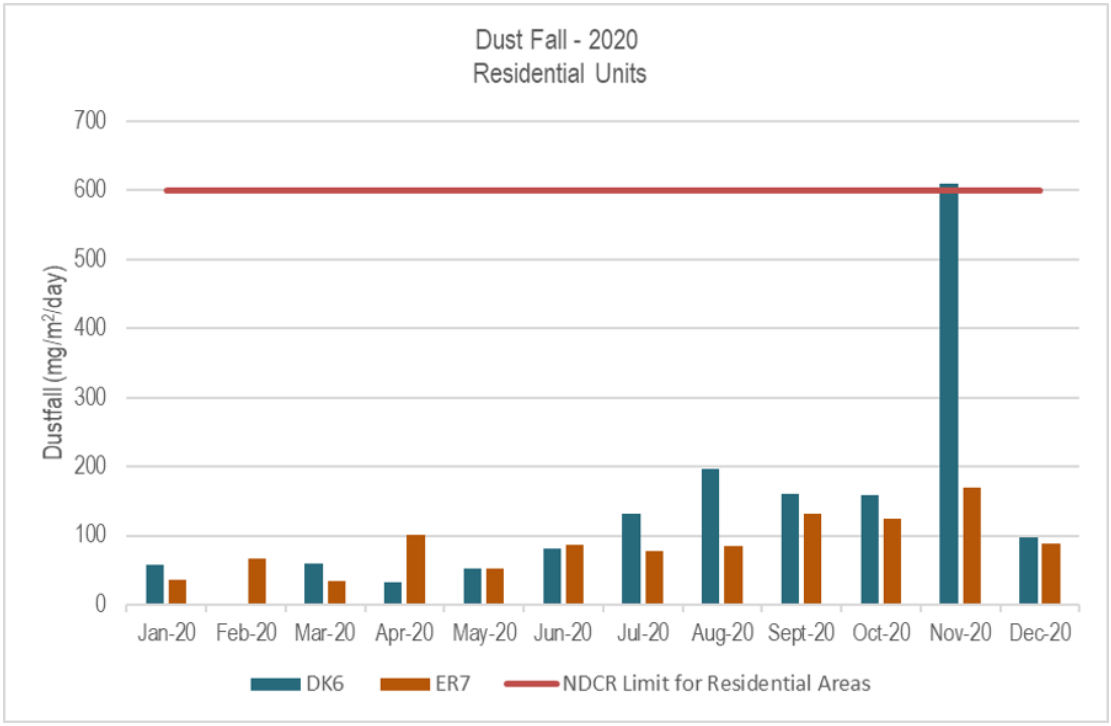


Figure 3.28 **Dustfall rates from January 2020 to December 2020 for Residential sites (Airshed, 2022).**

.

The dustfall monitoring results also show that, for the period January 2024 to December 2024, as shown in Figure 3.29, the ER7 site approached the residential limit in March of that year.

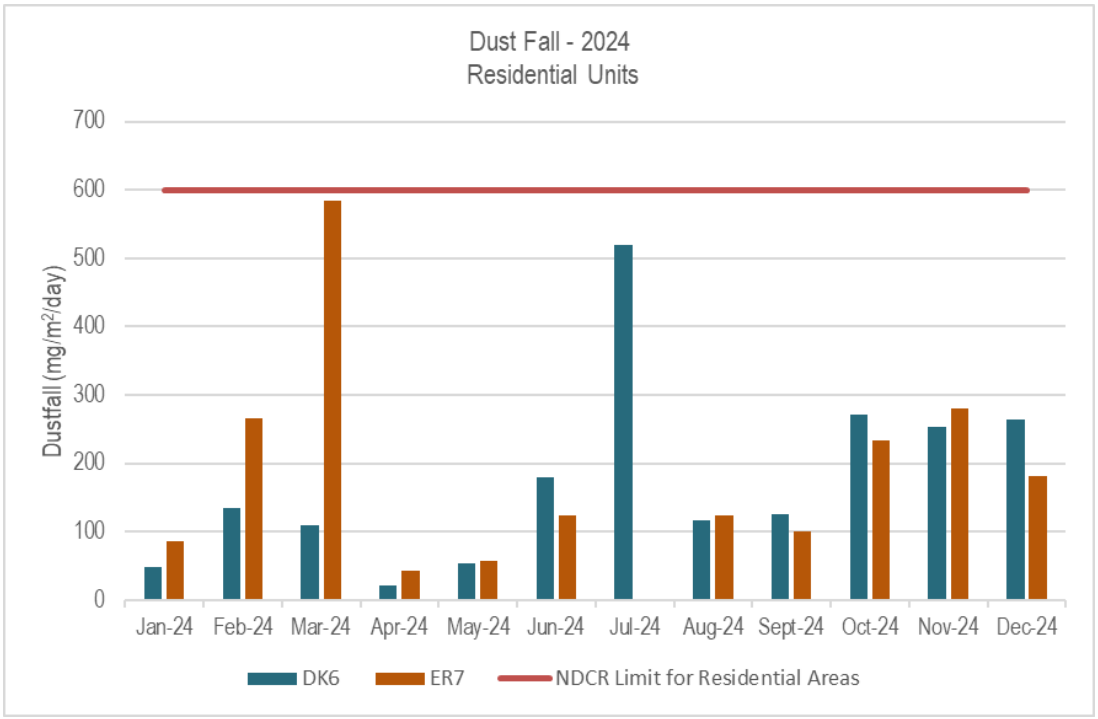


Figure 3.29 **Measured dustfall at the project site for the period January 2020 to September 2021 (Airshed, 2026).**



Figure 3.30 Kusasalethu Dustfall Monitoring Units (DMU) (Airshed, 2026).

3.7 Socio-Economic Baseline Conditions

3.7.1 General

The purpose of this section is to provide an overview of the demographic, land use, and human behavioural conditions of communities living near the Project. This information provides context regarding the potentially affected environment and receptors of radiation exposure as part of a Source-Pathway-Receptor (SPR) analysis. Within the assessment framework presented in Section 4.2, the SPR analysis serves as the basis for defining and justifying a discrete set of public exposure conditions.

The socio-economic baseline presented in this section is drawn from the Social Impact Assessment prepared for the Project by Equispectives Research and Consulting Services (Equispectives, 2026), supplemented by the Merafong City Local Municipality Integrated Development Plan 2025/26 and the West Rand District Municipality Integrated Development Plan 2025/26. The 2026 assessment was informed by a literature and policy review, secondary statistical analysis, and fieldwork and consultation undertaken in the project area to obtain primary qualitative data. Earlier studies of the communities in the area are summarised by AquiSim (2023) and are retained only where they provide descriptive detail.

Quantitative data is drawn from Statistics South Africa's Census 2011, Community Survey 2016 and Census 2022. Census 2022 results have been released only at the local municipal level, not at the ward level, so ward-level figures throughout this section are derived from Census 2011, categorised to the 2016 ward delineation, which is the latest ward-level data available. Two cautions apply to Census 2022 figures. First, Census 2022 recorded an undercount of approximately 31% of people and 30% of households, so while the results are robust at the aggregate level, they should be treated with caution at the sub-provincial level. Second, labour market indicators are not directly comparable across census rounds because the questionnaire has changed over time. Census 2022 was a de facto census with a reference night of 2 February 2022; Census 2011 used the night of 9 October 2011. The results should be interpreted as indicative of the population's characteristics in the area rather than as absolute values (Equispectives, 2026).

3.7.2 Locality and Municipal Context

Section 3.2 provides details on the regional geographical setting of the Project, which falls under the jurisdiction of the Merafong City Local Municipality within the West Rand District Municipality of the Gauteng Province (see Figure 3.31). The Merafong City LM is a Category B municipality covering an area of approximately 1,631.7 km^2 and comprising 28 wards, situated in the south-western part of the Gauteng Province (EIMS, 2026).

There are several communities located near the Project. Larger towns in the area include Carletonville and Fochville, which are located between 16 km and 20 km from the Project. The residential areas of Deelkraal, Elandsrand and Wedela are located near the site, within approximately 3 to 4 km. The residential areas of Carletonville, Khutsong, Fochville, Kokosi and West Wits Village have been excluded from the analysis as they fall outside the 5 km radius. Figure 3.31 also shows the mining infrastructure relative to the surrounding communities.

The Project are located adjacent to the operational Harmony Mponeng Operations and the Blyvooruitzicht Operations. These mining complexes include a variety of operational features, some of which are near the Project boundary. The project footprint and associated infrastructure fall within, or adjacent to, Ward 5, Ward 11, Ward 12, Ward 14, Ward 20, Ward 22, Ward 23 and Ward 27, based on the 2016 ward delineation,

which is the delineation used throughout this section because Census 2011 ward data is published on that basis and Census 2022 has not been released at ward level (Equispectives, 2026). Ward 5, Ward 11, Ward 14 and Ward 27 are characterised by a high incidence of mining activities. Ward 12, Ward 20, Ward 22 and Ward 23 have a more heterogeneous socio-economic and land-use profile. The following municipal wards and residential areas are located fully or partially within a 5 km radius around the Project:

- Ward 5: Blyvooruitzicht (The Village), Doornfontein, West Village, tailings storage facilities (excluded from analysis as the residential areas fall outside the 5 km radius; only some farming areas are within the radius).
- Ward 11: Wedela, Elandsrand village.
- Ward 12: Deelkraal, Welverdiend (outside a 5 km radius), parts of Khutsong (outside a 5 km radius), farms, tailings storage facilities.
- Ward 14: Numba Wani residence, West Wits Mining Village, Mohaleshoek informal settlement, farming areas, tailings storage facility, a portion of Fochville (excluded – residential areas are outside a 5 km radius).
- Ward 20: Wedela.
- Ward 22: Farms and smallholdings, tailings storage facility, part of Kokosi (outside a 5 km radius).
- Ward 23: Wedela.
- Ward 27: West Wits residences, Blyvooruitzicht (The Hill), TSFs (excluded – residential areas are outside the 5 km radius.

3.7.3 Land Use and Community Types

Gold mining has historically been the economic backbone of the Merafong area, shaping its settlement patterns, employment structures and social dynamics. However, the sector has contracted steadily over the past decade. Large-scale retrenchments occurred in the gold mining industry, and at the national level, the number of direct employees in gold mining has steadily declined since approximately 2010. Direct employment in gold mining declined by approximately 1.2 % between 2022 and 2023 and by 0.9 % to 2019 (pre-COVID-19) levels, reflecting reduced production and cost pressures. Large-scale retrenchments before 2020 significantly affected the mine-linked communities of Blyvooruitzicht, Wedela and Deelkraal. While the downward trend appears to be stabilising, the socio-economic consequences remain visible in elevated unemployment, increased informal activity and changing population dynamics across the study area (Equispectives, 2026). The Human Settlement Plan of Merafong City LM (2022/23) mentions the presence of informal settlements next to Deelkraal (on land belonging to Moira Mining) and south of Wedela (on land belonging to Randfontein Estates Ltd).

The Merafong City LM Integrated Development Plan 2025/26 pursues economic diversification under the "Reimagining Merafong 2035" strategy, aligning with the West Rand District's "Green is the New Gold" agenda and Gauteng's "Growing Gauteng Together 2030" strategy. Mining now contributes only about 3% of local Gross Value Added (2.95%), behind transport and logistics (17.96%), business services (15.25%), construction (13.64%), trade (10.76%), and manufacturing (6.49%), with agriculture at 0.03%. The municipality continues to aspire to a future state where the current scattered settlement patterns have developed into three distinct urban areas, namely the northern, central and southern areas, which are integrated as much as possible even though topographical barriers separate these areas. Each has its distinct strengths and constraints. The northern area comprises Welverdiend, Khutsong, Khutsong South, and Carletonville, while the central area comprises Blyvooruitzicht, West Wits, Driefontein, Elandsrand, Wedela, and Deelkraal. In the central area, most urban areas are unproclaimed mine villages, scattered in

a pattern. The southern area consists of Fochville, Kokosi, Greenspark and Losberg Industrial. The terrain is dolomitic, with associated sinkhole risk, posing significant challenges for land-use planning and infrastructure maintenance (Equispectives, 2026).

Figure 3.31 shows a 5 km radius around the Project surface infrastructure, along with potentially sensitive receptors within that radius. The following residential areas are near the Project:

- **Wedela** is situated between the Project and the Mponeng TSF. It was established in 1978 and granted municipal status in January 1990. Wedela is mostly a formal settlement, but there is an informal settlement on the edge of Wedela, and many houses have backyard shacks. It is currently located close to mining operations, which will not remain in place indefinitely.
- **Deelkraal Village** (formerly Deelkraal Estate) was once a mining village but has since passed into private ownership, with the owners in the process of having the estate declared a township. In the 2019/2020 IDP document for the Merafong City LM, Deelkraal is still listed as a mining village with very limited supportive land uses and economic potential, and it scores lowest among all the mining villages in the municipal area under the municipality's scoring criteria. The municipality will not take over services in the area and anticipates that Deelkraal will be demolished and the area rehabilitated. Fieldwork undertaken for the 2026 Social Impact Assessment records that the village is self-contained, with its own water and refuse arrangements, a clinic operating from a privately owned house, a club and a library, and that children attend school in Elandsrand, Fochville and Carletonville. The village has been without a mains electricity supply for several months following the plundering and burning of the local power station and the theft of power-line towers, resulting in sewage no longer being pumped and the village relying on water tankering. Rentals are comparatively low; around 38 houses stand vacant and are subject to vandalism and cable theft, and the village is under a court-supervised arrangement with contested ownership and rental terms. A boom gate controls access, and residents describe the village as relatively safe internally, with aspirations to develop a retirement village (Equispectives, 2026).
- A small settlement of informal occupiers is present in the project area. It is reported as a group of men, many of whom are said to be foreign nationals, some of whom have been residents since around 2009, with artisanal mining activity reported since around 2016. The occupants include cattle herders and artisanal miners (zama-zamas); family members reportedly do not live on site. They keep a reported 200 to 400 cattle, together with goats, pigs and poultry, which graze in the area and are sold at auction, and they cultivate maize, spinach, peppers and chillies. Cultivation and a cattle kraal, reportedly the only kraal in the immediate area, were observed on the proposed tailings storage facility footprint. The occupants were reported to be largely illiterate and to have limited English proficiency, with implications for engagement and accessibility; medicinal plants were observed in the area (Equispectives, 2026).
- The farming community comprises farms and smallholdings around the TSFs, except in the northeast of the Kusasalethu TSF, where the Mponeng infrastructure is located. Farming activities consist of crop farming, livestock farming, game breeding, and hunting. Some of the farms offer tourist activities. Some farms have workers residing on the farm, while workers from other farms do not reside there but somewhere in the vicinity.

Figure 3.32 shows the location of dwellings and structures relative to the Project [Keywords] that are not located in a town or a village. The number of dwelling groups has remained roughly the same, as observed in aerial photography. Some dwellings were demolished, but in other areas, new buildings were added. The most notable change is a new series of small buildings (about 30) that appear to be farmworker residences southwest of the Deelkraal TSF (indicated as a small residential area on the map).

Table 3.13 presents the breakdown of households by geo-type, shown as percentages of households for Census 2011 and Census 2022 at the provincial, district, and municipal levels, and for Census 2011 at the ward level using the 2016 ward delineation. The vast majority of households (97.4 %) in the Merafong City LM live in urban areas, with a small proportion (2.6 %) residing on farmland. Ward 22 has the highest share of farm geotype among the study wards at 15.5% (Equispectives, 2026).

Table 3.13 Breakdown of households according to geo-types (source: Census 2011, Census 2022) (Equispectives, 2026).

Area	Urban	Tribal or Traditional	Farm
Gauteng Province (2011)	97.6	0.9	1.5
Gauteng Province (2022)	97.2	1.2	1.6
West Rand DM (2011)	93.2	0.0	6.8
West Rand DM (2022)	92.5	0.0	7.5
Merafong City LM (2011)	96.9	0.0	3.1
Merafong City LM (2022)	97.4	0.0	2.6
Ward 5	100.0	0.0	0.0
Ward 11	100.0	0.0	0.0
Ward 12	95.6	0.0	4.4
Ward 14	98.4	0.0	1.6
Ward 20	100.0	0.0	0.0
Ward 22	84.5	0.0	15.5
Ward 23	100.0	0.0	0.0
Ward 27	100.0	0.0	0.0

3.7.3.1 Formal Residential Structure Communities

A formal dwelling can be described as "*A structure built according to approved plans, i.e., house on a separate stand, flat or apartment, townhouse, a room in a backyard or rooms or flatlet elsewhere*" (Statistics South Africa, 2012). In some areas, there may be both formal and informal dwellings on a stand, creating a community with *a mix of dwelling types*.

3.7.3.2 Informal Residential Structure Communities

An informal dwelling can be described as "*A makeshift structure not approved by a local authority and not intended as a permanent dwelling. Typically built with found materials (corrugated iron, cardboard, plastic, etc.) and is contrasted with formal dwellings and traditional dwellings*" (Statistics South Africa, 2012).

3.7.3.3 Commercial Agricultural Communities

Commercial agriculture includes farms where the farmer earns a livelihood from agriculture, such as crop, livestock or game farming. Areas with smallholdings are categorised according to their character. If the residents of the smallholdings practise agriculture, they are grouped with commercial agriculture; if they reside in the area or have a business on the smallholding unrelated to agriculture, the area is classified as formal residential.

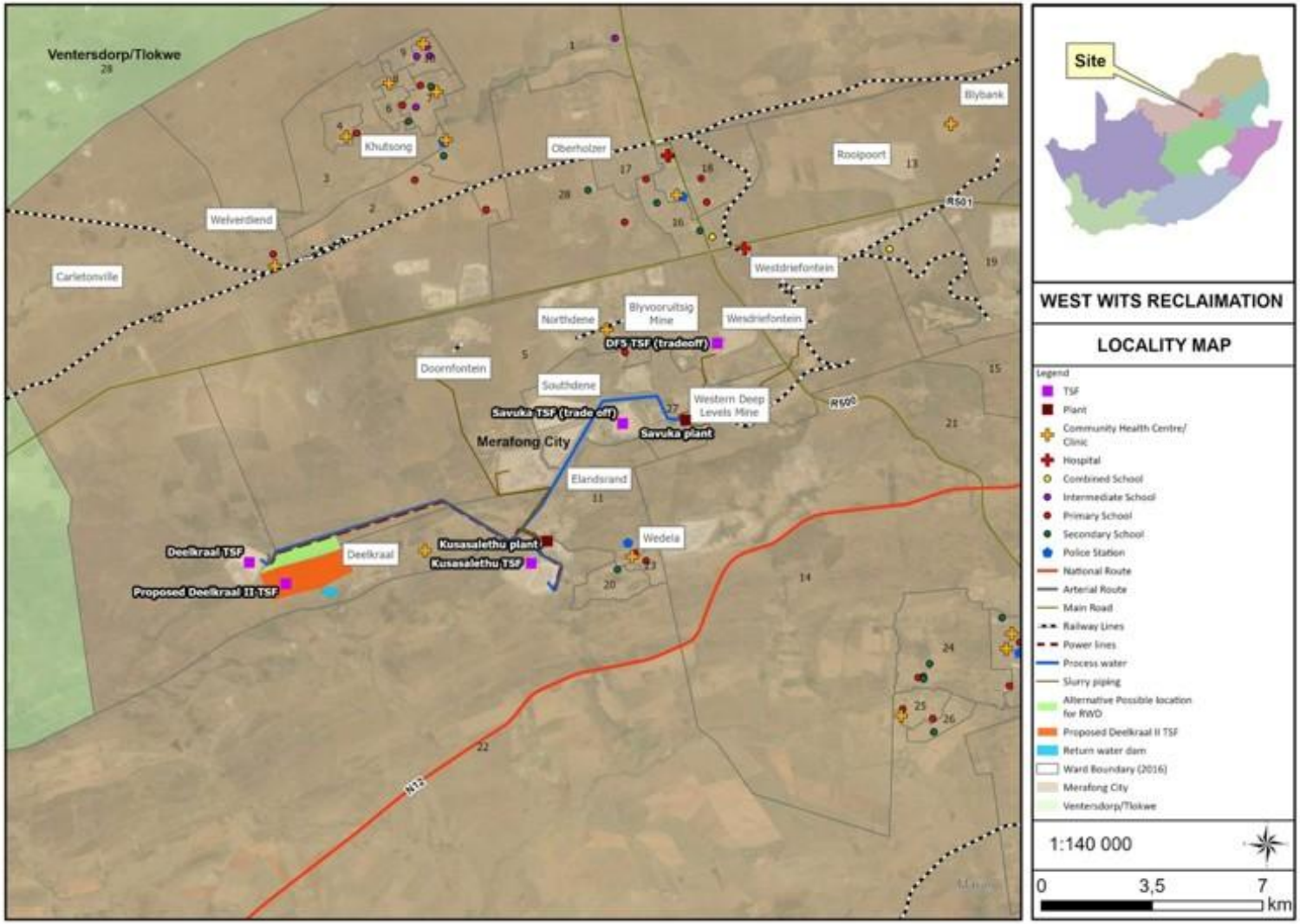


Figure 3.31 Regional locality map showing the location of the Project (Equispectives, 2026).

3.7.3.4 Small-scale Subsistence Farming

Small-scale subsistence farming can be described as large-scale food gardening on land other than someone's backyard. Different members of the community usually cultivate the land, and they may belong to a formalised group. Food gardens in the backyard of an organisation, such as a school or crèche, would also fall into this category. Keeping livestock in the community or on its outskirts would fall under this group. Agricultural projects conducted as part of a mine's Social and Labour Plan can exhibit characteristics of both commercial agriculture and subsistence farming. To classify these projects, the following guideline is used. If a project has reached a stage at which it is sustainable and functions with minimal to no input from the mine, it is classified as commercial agriculture. However, if the mine remains heavily involved, it is classified as small-scale subsistence farming, as the project has not yet demonstrated its sustainability.

3.7.4 Demographics and Socioeconomic Characteristics

3.7.4.1 Demographics

According to Census 2022, reported in Equispectives (2026), Table 3.14 shows that the population of the West Rand District increased by 21.6 % between 2011 and 2022, from 821,191 to 998,466, while the population of the Merafong City LM increased by 14.2 % over the same period, from 197,520 to 225,476. The West Rand remains the least-populated district in Gauteng, and Merafong City the least-populated municipality within the West Rand. The central mining belt has experienced significant population declines in recent years, while the northern and southern urban areas have seen moderate increases; the decline is expected to level off in the long run as the economy enters a post-mining stage.

Table 3.14 Change in population, households and population density between 2011 and 2022 (source: Census 2011 and Census 2022) (Equispectives, 2026).

	Census 2011	Census 2022	Difference
Gauteng Province			
Population	12,272,263	15,099,422	23.04 %
Households	3,908,826	5,318,665	36.07 %
Average household size	3.14	2.84	
Population density (persons per km^2)	675.12	830.64	
West Rand District Municipality			
Population	821,191	998,466	21.59 %
Households	267,460	356,530	33.30 %
Average household size	3.07	2.80	
Population density (persons per km^2)	200.93	244.30	
Merafong City Local Municipality			
Population	197,520	225,476	14.15 %
Households	66,624	77,599	16.47 %
Average household size	2.96	2.91	
Population density (persons per km^2)	121.10	138.24	

Household numbers have risen faster than population growth. Between 2011 and 2022, the number of households in Merafong City increased by about 16,5 %, from 66 624 to 77 599, compared to 36 % in Gauteng and 33 % in the West Rand (see Table 3.14). The average household size declined slightly to 2.9 persons per household, consistent with higher rates of single-person and migrant-worker households typical of mining regions. This reflects a demographic trend of smaller, more dispersed households, partly due to labour migration and changing family structures.

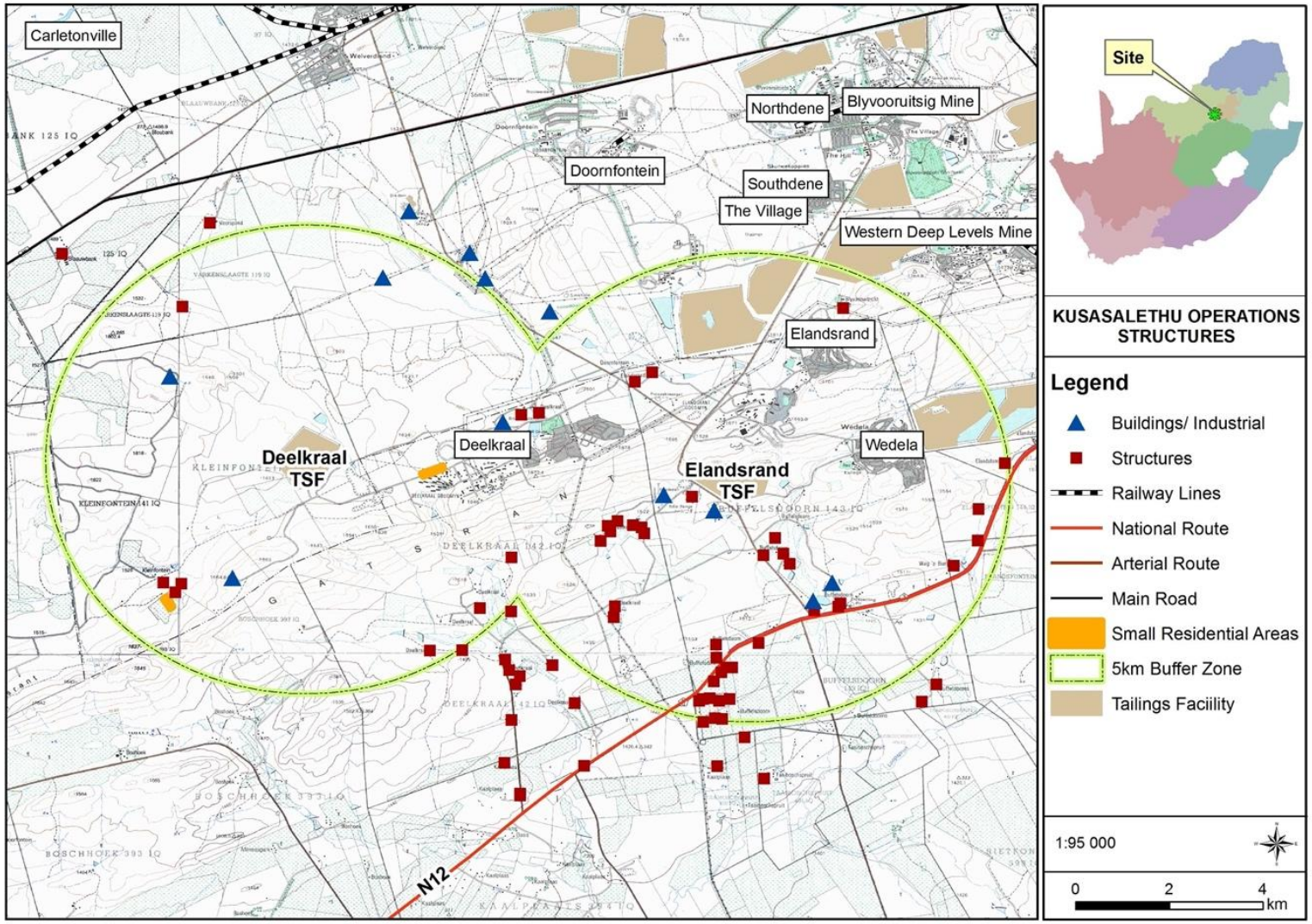


Figure 3.32 Map indicating the study area used for the Project Baseline Social and Land Use Assessment (AquiSim, 2023).

According to Census 2022, Table 3.15 shows that the Black African population group constitutes the largest proportion of Merafong's population at 89.4 %, followed by the White (8.8 %) and Coloured (1.3 %) population groups. In Ward 12, which includes Deelkraal and Welverdiend, more than half of the population belonged to the White population group, while in Ward 14, just over a third did (EIMS, 2026).

Table 3.15 Breakdown of the population distribution in the different areas (source: Census 2022) (Equispectives, 2026).

Population	West Rand	Merafong City	Ward 11	Ward 12	Ward 20	Ward 22	Ward 23
Black	650,132	201,553	6,610	2,107	8,652	7,449	6,699
Coloured	20,550	2,931	27	30	2	107	20
Indian	9,433	722	2	14	9	9	6
White	137,041	19,886	336	2,576	5	427	4
Other	3,838	321	23	29	23	34	49
Total	820,995	225,413	6,997	4,757	8,691	8,026	6,777

3.7.4.2 Family Structure

From Figure 3.33, Census 2022 records that 55% of households in the Merafong City LM consist of one or two persons, and that the average household size has declined to approximately 2.91 persons, consistent with the higher rates of single-person and migrant-worker households typical of mining regions. Wards 5 and 27 have particularly high shares of single-person households, above 65 %, while Wards 12 and 20 have slightly larger average household sizes (Equispectives, 2026).

The ward-level breakdown in Figure 3.33 is based on Census 2011 mapped to the 2016 ward delineation, as Census 2022 results have been released only to the local municipal level. It shows that more than half of households at the provincial, regional, local, and ward levels consisted of 1 to 2 people, except in Ward 12 and Ward 22, where the incidence was just under half, and that Ward 11 (68.34 %), where Wedela and Elandsrand are located, had the highest incidence of households consisting of only one person.

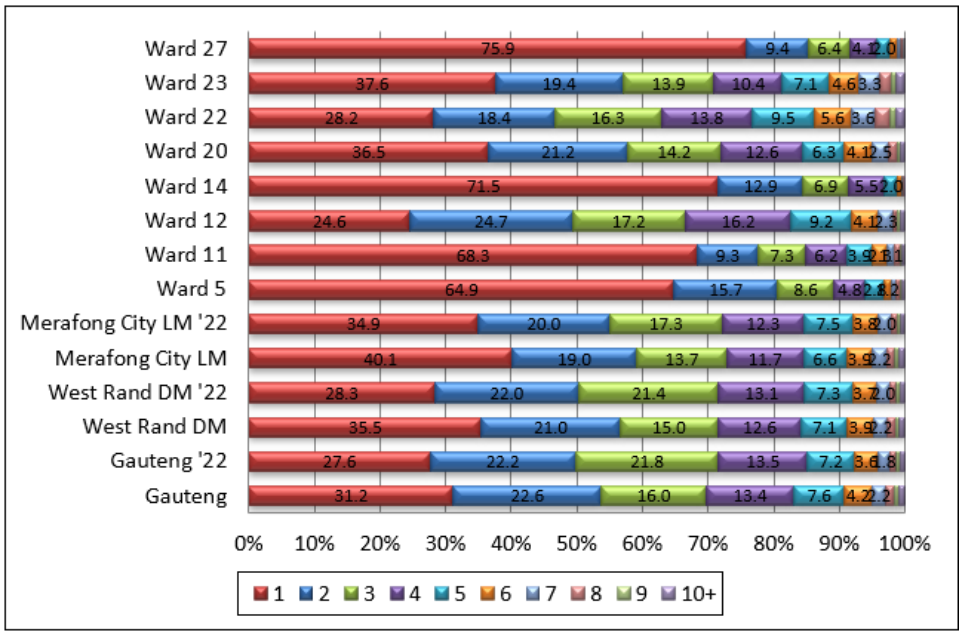


Figure 3.33 Household size (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

Census 2011 data summarised in Table 3.16 shows that males headed more than two-thirds of households in Merafong City LM. At the ward level, this proportion ranged from about two-thirds to more than 90 %. The Community Survey 2016 shows that between 2011 and 2016, the proportion of female-headed households remained roughly the same. Female-headed households are often less financially well-off than similar male-headed households and are considered more vulnerable.

Table 3.16 Gender of the head of household (source: Census 2011) (AquiSim, 2023).

Sex of head of household	West Rand	Merafong City	Ward 11	Ward 12	Ward 20	Ward 22	Ward 23
Male	200,514	49,583	3,172	1,121	2,182	1,501	1,633
Female	87,604	20,752	413	421	1,052	912	769
Total	288,118	70,335	3,585	1,543	3,234	2,414	2,402

Census 2022 records an average age of approximately 30.4 years in the Merafong City LM, similar to the West Rand District (30.65) and Gauteng Province (30.97) averages and up from 29.41 in 2011. From Figure 3.34, the age distribution suggests a maturing population, with 24% of residents under 15 years, 36% aged 15 to 34 years, and 12% aged 50 years or older. Ward-level variation is marked: Ward 5 and Ward 27 have higher proportions of adults aged 35 to 64 years, while Ward 20 has a comparatively younger population, with over 49 % of residents under 25 years, and Ward 11 recorded the lowest average age among the study wards. Sex distribution is nearly balanced at 51% male and 49% female, but Ward 5, Ward 14, and Ward 27 exhibit male-dominant ratios above 65%, consistent with the presence of mining operations that attract migrant male workers (Equispectives, 2026).

Home language data indicate linguistic diversity, with Setswana (28 %), isiXhosa (26 %) and Sesotho (21 %) dominant across the local area. Afrikaans (9 %) and English (2 %) are less prevalent overall but more common in Ward 12 and Ward 14. Communication and engagement in the area should therefore be conducted primarily in Setswana, isiXhosa, and Sesotho, with Afrikaans and English used where appropriate (Equispectives, 2026).

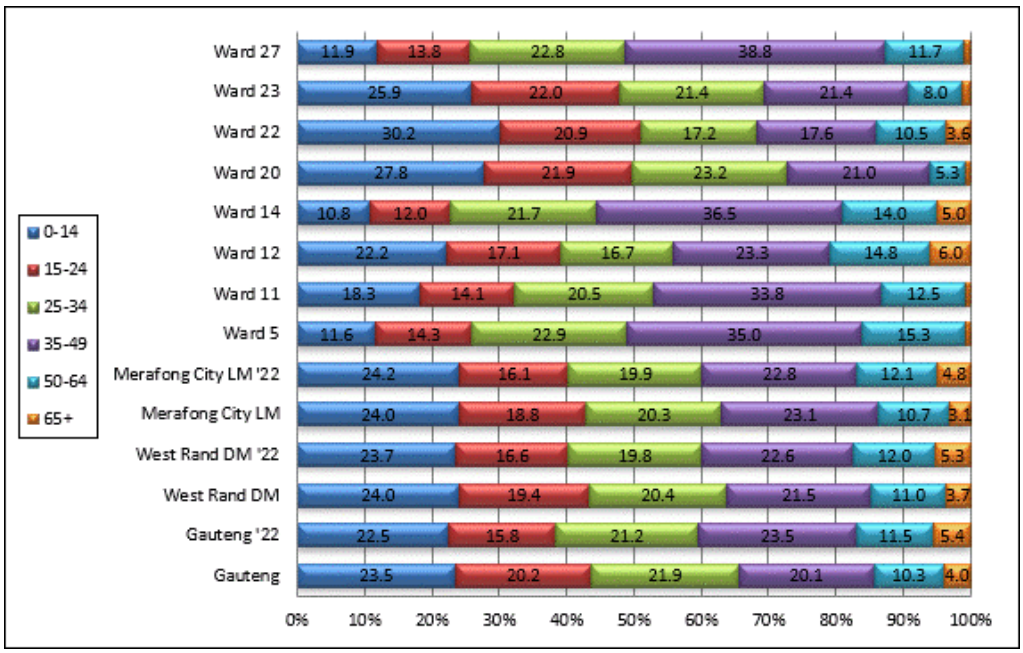


Figure 3.34 Age distribution of the population (shown in percentage; source: Census 2011, Census 2022) (Equispectives, 2026).

Child-headed households are considered extremely vulnerable, as there is usually no adult to provide them with food and other necessities, and they often rely on the kindness of neighbours and other family members for survival. A child who heads a household often lacks the experience and maturity required to raise his or her siblings and must drop out of school to do so. The ward-level data in Table 3.17, based on Census 2011 mapped to the 2016 ward delineation, shows that Ward 20 (1.1 %), Ward 22 (1.4 %) and Ward 23 (1.2 %) had the highest incidence of child-headed households with the age of the heads of household between 10 and 19 years, slightly above the municipal level for Merafong City LM (1 %). The areas with the highest incidence of heads of household who have reached retirement age were Ward 12 (9.7%) and Ward 22 (8.9%).

Census 2022 shows that the population's ageing has continued. The aged dependency ratio for the Merafong City LM rose from 4.31 in 2011 to 6.83 in 2022, and the total dependency ratio rose from 37.30 to 40.95, compared with 40.83 for the West Rand District and 38.85 for Gauteng Province. Youth dependency also increased, from 32.98 to 34.13. The employed dependency ratio remains above 66, signalling a relatively small, employed base supporting a large number of dependents. This suggests both a youthful population structure and gradual population ageing, with many people remaining in the area after retirement (Equispectives, 2026).

Table 3.17 Gender distribution (source: Census 2011) (AquiSim, 2023).

Age of head of household	West Rand	Merafong City	Ward 11	Ward 12	Ward 20	Ward 22	Ward 23
10-19 years	2,529	694	14	5	34	33	29
20-34 years	92,309	22,139	910	348	1,256	724	825
35-64 years	171,718	43,016	2,622	1,040	1,886	1,441	1,485
65+ years	21,561	4,485	39	150	58	215	63
Total	288,118	70,335	3,585	1,543	3,234	2,414	2,402

3.7.4.3 Socio-Economic Conditions

According to Figure 3.35, Census 2022 records that approximately 46.5% of working-age residents (15 to 64 years) in the Merafong City LM were employed, while 17% were unemployed and a further 33% were economically inactive. Employment rates are notably higher in Ward 11, Ward 14, and Ward 27, above 65 %, and lower in Ward 20 and Ward 22, around 35 to 45 %. It must be noted that large-scale retrenchments have occurred in the gold mining industry since 2012, and that the mine-linked settlements of Blyvooruitzicht, Wedela and Deelkraal were significantly affected by retrenchments prior to 2020.

Formal sector employment dominates, accounting for over 80% of all jobs, with the remainder in informal or private household work; mining, manufacturing, and public services remain the leading employment sectors. The gendered nature of employment is apparent, with men overrepresented in mining and industrial work and women more likely to be engaged in domestic work or the informal economy. The overall labour absorption rate remains below the provincial average, consistent with post-mining economic decline and limited local diversification (Equispectives, 2026).

Educational attainment in the Merafong City LM has improved since 2011, although disparities remain. Approximately 53 % of adults aged 20 years and older have some secondary education, and 38 % have completed Grade 12 or higher, while only about 7 % hold post-secondary or tertiary qualifications. Wards 12 and 14 show the highest proportion of residents with matric or higher, while Wards 5 and 22 display larger shares of residents with incomplete primary or secondary schooling. The share of adults without any schooling has declined from over 6% in 2011 to below 5% in 2022 (Equispectives, 2026).

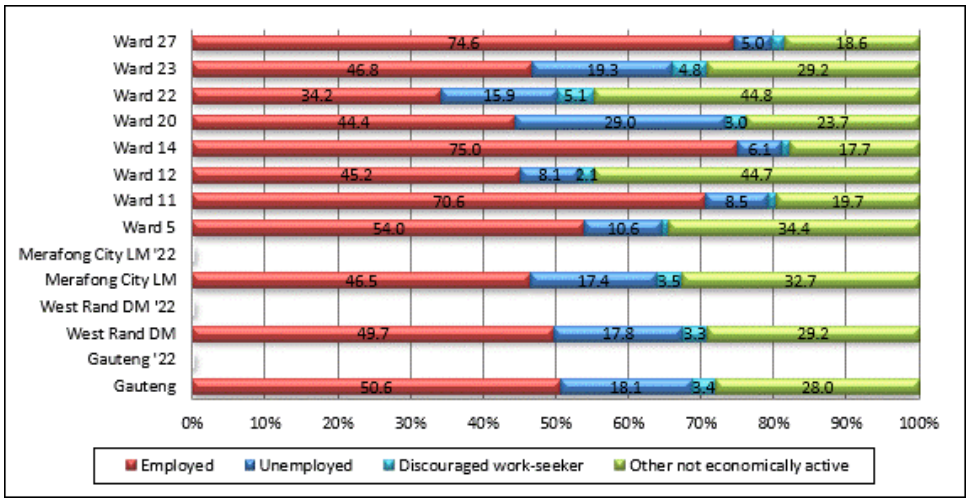


Figure 3.35 Labour status (those aged between 15 - 65 years, shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

Census 2022 records that around 21 % of households in the Merafong City LM earn less than R19,601 per year, significantly fewer than in 2011 but still indicative of multidimensional poverty in certain wards. Ward 22 and Ward 20 have the highest proportion of low-income households, at over 35 %, while Wards 11 and 27 have a greater concentration of middle-income earners in the R38,200 to R76,400 per year range. Fewer than 2% of households earn more than R1.2 million annually, and the majority fall within the R19,601 to R76,400 range, which aligns with the lower-middle-income bracket typical of former mining towns (Equispectives, 2026). Ward-level data on the 2016 delineation, summarised in Table 3.18, show that Ward 20, Ward 22 and Ward 23 had the highest incidence of households with no income and the highest proportion of households earning less than R19,601, placing them below or just above the lower-bound poverty line. More recent indicators reported in the Draft Integrated Development Plan for Merafong City 2025/26 (EIMS, 2026) show that in 2020, approximately 53.1% of the Merafong City LM population was living below the upper-bound poverty line, the second-highest in the West Rand District after Rand West City (54.2%).

Table 3.18 Annual household income (source: Census 2011, shown in percentage) (AquiSim, 2023).

Annual household income	West Rand	Merafong City	Ward 11	Ward 12	Ward 20	Ward 22	Ward 23
No income	16.08	15.97	4.89	10.08	16.64	23.24	19.80
R 1 - R 4,800	3.98	3.99	0.85	1.13	5.59	4.03	2.32
R 4,801 – R 9,600	5.84	5.88	1.04	3.43	5.76	8.13	5.74
R 9,601 – R 19,600	12.98	11.12	2.90	7.98	8.61	23.21	7.82
R 19,601 – R 38,200	17.40	14.94	7.25	13.43	16.04	20.06	13.28
R 38,201 – R 76,400	19.15	26.43	60.01	19.52	35.12	12.09	29.55
R 76,401 – R 153,800	10.32	10.99	12.01	19.83	9.45	4.71	14.89
R 153,801 – R 307,600	7.57	6.58	8.00	16.94	2.29	2.43	4.85
R 307,601 – R 614,400	4.46	3.01	2.61	6.27	0.39	1.38	1.38
R 614,001 - R 1,228,800	1.54	0.75	0.28	0.98	0.04	0.12	0.14
R 1 228 801 - R 2 457 600	0.41	0.19	0.06	0.14	0.04	0.14	0.14
R 2 457 601 or more	0.25	0.14	0.10	0.23	0.04	0.43	0.09
Unspecified	0.00	0.00	0.00	0.07	0.00	0.04	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Less than R19,601	38.89	36.96	9.69	22.61	36.60	58.61	35.67

Multidimensional poverty in the municipality eased marginally between 2011 and 2016: the poverty headcount in the Merafong City LM declined from 8.5 % to 6.4 % and the intensity of poverty from 44.5 % to 43.6 %, reducing the SAMPI score from 0.038 to 0.028. The same pattern is evident at district and provincial level, with the West Rand recording a SAMPI decline from 0.035 to 0.028. Although Merafong's poverty levels are lower than those of many mining-dependent municipalities in South Africa, economic vulnerability persists, particularly in wards affected by mine closures and limited employment diversification (Equispectives, 2026).

Income inequality has remained largely unchanged, with the district Gini coefficient remaining just above 0.6 from 2012 to 2020, and the contribution of mining to the West Rand's economic output has declined from 31% in 1996 to an estimated 19.5% by 2021 (EIMS, 2026).

Consultation and fieldwork undertaken for Equispectives (2026) recorded very high local unemployment across the surrounding settlements, widespread dependence on social grants, and growing reliance on informal work, together with substance-abuse and crime problems including drug dealing, stock theft and the theft of Eskom infrastructure.

Statistics South Africa (2015) calculated the Food Poverty Line (FPL) for the Gauteng Province as R339 per capita per month for 2011, the value below which individuals are unable to purchase or consume enough food to meet the minimum per capita per day energy requirement for good health. The FPL is one of three poverty lines, the others being the upper-bound poverty line (UBPL) and the lower-bound poverty line (LBPL). Both the LBPL and the UBPL include a non-food component. Individuals at the LBPL lack sufficient resources to purchase both adequate food and non-food items and are forced to sacrifice food to obtain essential non-food items, whereas individuals at the UBPL can purchase both adequate food and non-food items. The LBPL for the Gauteng Province was R523 per capita per month in 2011, and the UBPL was R963 per capita per month. More recent poverty lines than the rebased 2011 poverty lines are not available. Based on this, a household of three needed an annual income of approximately R18,800 in 2011 to be just above the LBPL. Using the average CPI for 2019 (Statistics South Africa, 2020), this amount would currently be approximately R27,218. It must be noted, however, that poorer households tend to experience higher inflation over time and are more exposed to price changes in goods such as volatile paraffin and food (Oosthuizen, 2013). This is due to differing expenditure patterns: poorer households tend to allocate a larger share of their budgets to food. These households also experience relatively higher exposure to inflation from non-alcoholic beverages, tobacco products, clothing and footwear, household fuel and power and personal care products.

3.7.5 Residential Areas and Household Structure

According to Figure 3.36, Census 2022 records that most dwellings in the Merafong City LM are formal houses or brick structures on separate stands, accounting for approximately 83% of households. However, informal dwellings remain widespread, accounting for more than 20% of households in Ward 22 and Ward 23. Ward 14 has a notable proportion of flats and apartments, at around 40 % of households, reflecting more compact, higher-density housing associated with mine accommodation. Tenure status shows that 35 % of households rent their dwellings, 32 % own their homes outright, and 27 % occupy them rent-free; renting exceeds 70 % in Ward 11, Ward 14, and Ward 27, while owner-occupied, fully paid-off dwellings are more prevalent in Ward 22 and Ward 23. These figures indicate a relatively mobile and mixed housing market shaped by labour migration and the fluctuating local economy (Equispectives, 2026).

Ward-level data on the 2016 delineation, summarised in Table 3.19, show that Ward 12 (90.1 %) and Ward 20 (79.4 %) had the highest incidence of households living in brick or concrete dwellings, such as a dwelling

in a separate yard, a block of flats, a cluster house or townhouse in a complex, or a semi-detached house. Ward 22 (30.4 %) had the highest incidence of informal dwellings that were not in someone's backyard, while Ward 23 (21.0 %) had the highest incidence of households living in informal dwellings in someone's backyard. Ward 11 had the highest incidence of households living in a flat or apartment in a block of flats or a dwelling that could be described as 'Other'. Given the high incidence of mining activities in these wards, the households are most likely living in mine residences. The Merafong City LM IDP (2019/2020) indicated the following urban developments are in the pipeline:

- Ward 12: Elija Barayi Village – west of Carletonville, next to Welverdiend. This development is planned to consist of about 8,150 Reconstruction and Development Programme (RDP)/Breaking New Ground (BNG) houses and 2,900 Gap houses. According to the 2022/2023 Merafong City LM IDP, this development appears to be in progress.
- Ward 12: Khutsong South – expansions in the current Khutsong South area. This appears to be in progress according to the 2022/23 Merafong City LM IDP.
- Ward 22 and Ward 23: Wedela Extension 4 – an undeveloped area next to Wedela (furthest from mining infrastructure and in an area where agricultural activities occur). This development will consider the need for additional business and institutional activities. A strip of multi-use businesses is envisioned, and the design and layout will focus on an 'Agri village' theme. The 2022/23 Merafong City LM IDP designates this area as an industrial development area, but the Merafong City LM Human Development Plan (2022/23) states that it remains undeveloped.

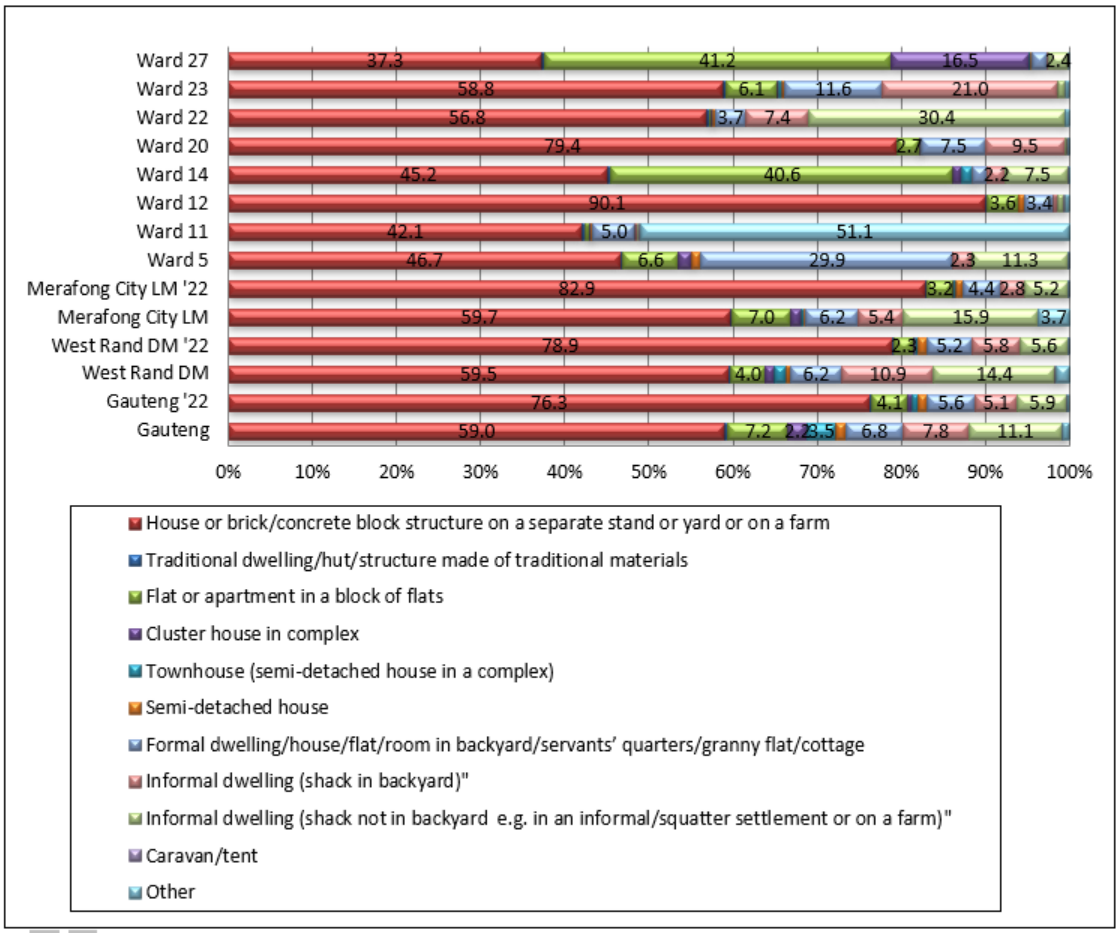


Figure 3.36 Dwelling types (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

Table 3.19 Main dwelling types (households, source: Census 2011) (AquiSim, 2023).

Dwelling Type	West Rand	Merafong City	Ward 11	Ward 12	Ward 20	Ward 22	Ward 23
House or brick/concrete block structure on a separate stand or yard or a farm	159,124	39,776	1,494	1,363	2,563	1,241	1,406
Traditional dwelling/hut/structure made of traditional materials	758	137	13	3	4	7	7
Flat or apartment in a block of flats	10,682	4,634	19	55	87	6	147
Cluster house in a complex	3,197	846	4	1	1	2	4
Townhouse (semi-detached house in a complex)	3,546	204	0	0	1	0	9
Semi-detached house	1,252	174	10	12	4	7	7
House/flat/room in the backyard	13,130	2,867	175	43	202	78	274
Informal dwelling (shack in the backyard)	29,108	3,576	9	7	306	163	501
Informal dwelling (shack not in backyard, e.g., in an informal/squatter settlement or on a farm)	38,629	10,600	7	11	9	664	22
Room/flatlet on a property or larger dwelling/servants quarters/granny flat	3,457	1,292	4	8	41	3	3
Caravan/tent	252	36	4	3	1	0	0
Other	4,255	2,482	1,813	8	7	13	10
Unspecified	1,312	352	13	21	4	23	5
Not applicable	19,580	3,430	23	8	4	207	8
Total	288,282	70,406	3,586	1,543	3,234	2,414	2,402

Houses in the Elandsrand and Deelkraal residential areas are all brick structures (see Figure 3.37 and Figure 3.38). The Wedela area contains, in addition to the brick-built housing constructed by the mine, several RDP houses and informal dwellings. Figure 3.39presents a distant view of the western portion of RDP houses in the Wedela residential area from the Kusasalethu TSF. In the agricultural areas, the farmhouses are brick structures with mostly metal roofs (see Figure 3.40). Fieldwork for Equispectives (2026) records that around 38 houses in Deelkraal Village stand vacant and are subject to vandalism and cable theft, and that residents on farms and smallholdings have reported seismic tremors and the cracking of houses, attributed variously to mining-related seismicity and to dolomitic ground movement (Equispectives, 2026).

According to AquiSim (2023), about half of the farms in the area have workers residing on the farm, presumably in permanent brick-built structures, while workers from other farms reside elsewhere in the vicinity.

3.7.6 Social Infrastructure and Services

3.7.6.1 Social Infrastructure

The infrastructure available to households indicates the vulnerability of residents in a specific area. A lack of infrastructure, or the use of a specific type of infrastructure, can make residents more vulnerable to exposure pathways. The 2022/23 Merafong City LM IDP does not indicate the number of available facilities in terms of Early Childhood Centres, primary schools, secondary schools, FET colleges, schools for mentally disabled students, sports stadiums, swimming pools, community halls, parks, resorts, libraries, multi-purpose recreational community centres, clinics, or public hospitals. It does indicate that Wedela needs a secondary school and an informal market. The 2022/23 Merafong City LM IDP indicates that there are community sports facilities in Wedela.



Figure 3.37 Houses in the Elandsrand residential area (AquiSim, 2023).



Figure 3.38 Houses in Deelkraal estate (AquiSim, 2023).



Figure 3.39 Wedela as viewed from the Kusasalethu TSF (AquiSim, 2023).



Figure 3.40 Housing structures in agricultural areas (AquiSim, 2023).

The social infrastructure in the area around the site is limited and has deteriorated further since the earlier studies. From the fieldwork undertaken for Equispectives (2026), the Deelkraal Village is a self-contained former mine village with its own water and refuse arrangements, a clinic operating from a privately owned house, a club and a library; children attend school in Elandsrand, Fochville and Carletonville. The village has been without a mains electricity supply for several months following the power being switched off, the plundering and burning of the local power station, and the theft of power-line towers, resulting in sewage no longer being pumped and the village relying on water tankering. The resident population includes a significant number of elderly and vulnerable people, including persons dependent on oxygen. Rentals are comparatively low, and around 38 houses are vacant and subject to vandalism and cable theft. There is internal social tension over rent and service payments, and the village is subject to a court-supervised arrangement, with ownership and rental arrangements contested. Despite these pressures, residents describe the village as relatively safe internally, with boom-gate controlled access and good inter-group relations, and note aspirations to develop a retirement village and other facilities.

In Wedela, there is a community hall, shops, a technical high school, two primary schools, several preschools, a police station, a clinic, a library, a soccer field, and play areas for children. Elandsrand has a community hall and a nursery school, but no other schools. Some of the farms in the area offer accommodation or hunting, with the focus shifting to ecotourism and game breeding, and there are private game reserves. The Westgold hunting club, a private game reserve and a guesthouse facility are situated in the area opposite the Elandsrand TSF. Across the surrounding settlements, fieldwork recorded deteriorating municipal services and roads, with some areas accessible only by four-wheel-drive vehicle (Equispectives, 2026).

Taking into consideration the downscaling of the mining activities in the area and the plans indicated for the mining villages in the Merafong City LM IDP (2019/20), it is anticipated that activities and social infrastructure in areas that were rated as low-potential areas for future development will decline, while in the high-potential areas it will increase.

In terms of schooling, Deelkraal Estate has a nursery school through Grade R, and some buses and minibuses transport children to primary and secondary schools outside the area. The estate also boasts a government clinic, shops (see Figure 3.41), and several recreational facilities (see Figure 3.42).

3.7.6.2 Community Activities

Activities that take place in a community differ from community to community. Based on similar studies over time in other areas, people who live in areas with high unemployment tend to spend more time outside. They socialise outside; children tend to play outside for most of the day, as many households in these areas cannot afford to send their children to daycare. Informal housing tends to be very cold in winter and very hot in summer, and is usually quite small inside; as such, these residents prefer to be outside.

In many lower-income areas, there are usually makeshift sports fields where residents can play soccer or other sports. Incidences of food gardens in areas with high levels of poverty and unemployment are usually higher than in other areas, as many residents do not have the means to buy all their food, and a higher proportion of people have time available to tend to a food garden. The 2016 Community Survey shows that 14.85% of people in Merafong City LM walk to their educational institutions. As a result of downsizing in the gold mining industry, it is anticipated that, in certain residential areas, the number of people spending time outside will increase, as they are no longer employed.



Figure 3.41 Supermarket in Deelkraal Estate (AquiSim, 2023).



Figure 3.42 Recreational facilities at Deelkraal Dam (AquiSim, 2023).

3.7.6.3 Access to Water

According to AquiSim (2023), the Community Survey 2016 showed that approximately 6.7 % of households in Merafong City LM reported not having access to safe drinking water, while about 12.6 % of people rated the overall quality of water services as poor. Approximately 22.2% of households reported experiencing municipal water interruptions in the preceding three months, while 15.0% reported interruptions lasting more than two days. In Merafong City, LM, 40.8 % of households that experienced water interruptions reported using a water tanker, 22.6 % another water source (not specified which alternative sources), and about 28 % used no alternative water source during interruptions. Most people (80.9%) who do not have access to piped water inside their dwellings or yards have access to a water source within 200 metres of their dwellings or yards.

From Figure 3.43, Census 2022 records that approximately 95 % of households in the Merafong City LM receive water from a regional or local water scheme operated by the municipality or another water services provider, with boreholes and alternative sources (such as rainwater or tankers) serving fewer than 5 % of households. Ward 22, which consists mostly of farms and smallholdings, shows the lowest municipal supply coverage at around 77% and the highest incidence of households accessing water from boreholes. These findings indicate that while overall water infrastructure coverage is good, there are localised gaps in reliability and access (Equispectives, 2026).

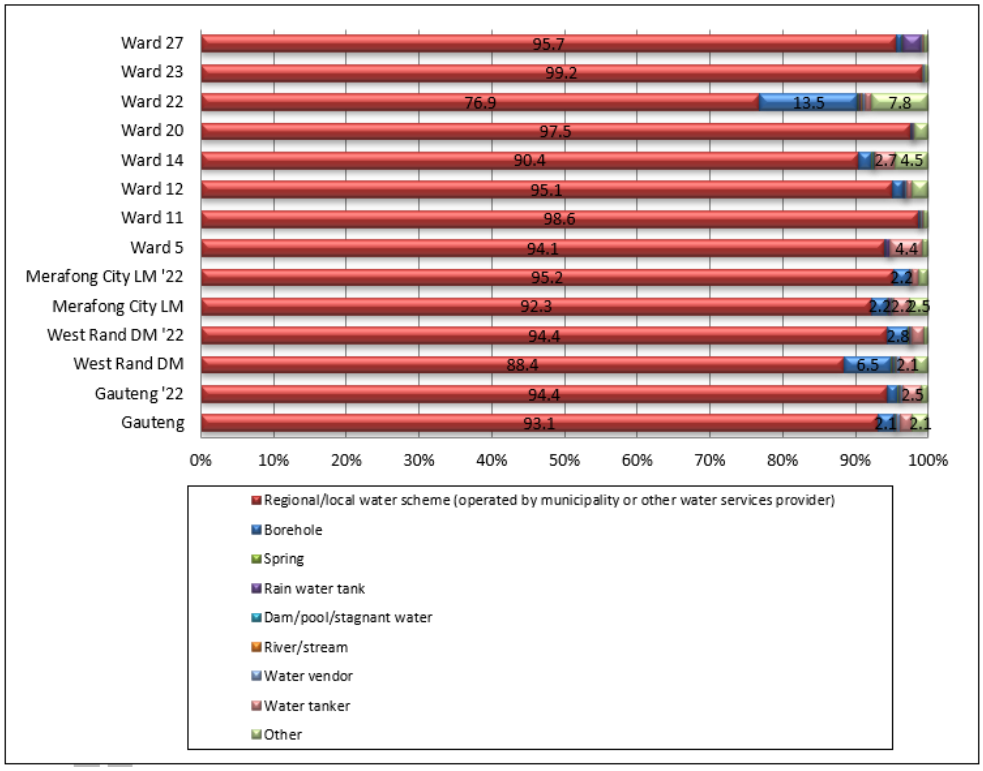


Figure 3.43 Water Source (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

Figure 3.44 shows that in 2022, 82 % of households in the Merafong City LM had piped water inside the dwelling, and a further 14 % had access to piped water within the yard, with Ward 11 exceeding 90 % internal access and Wards 12 and 22 below 35 %; only 1 to 2 % of households have no access to piped water and rely on communal sources. The ward-level breakdown in the tables below is based on Census 2011 mapped to the 2016 ward delineation, as Census 2022 results have not been released at ward level (Equispectives, 2026).

Fieldwork undertaken for Equispectives (2026) shows that these municipal averages mask acute, localised failure. Deelkraal Village maintains its own water arrangements and has relied on water tankering for an extended period because prolonged electricity outages have halted sewage pumping and disrupted the water supply. On surrounding farms and smallholdings, on-farm dams and streams are, in some cases, the only water sources for livestock, game, and people, and they depend in part on runoff from the mine. Residents of Deelkraal Village have raised concerns about the consequences of a potential tailings facility or pipeline failure, given that the local stream flows toward Potchefstroom.

3.7.6.4 Refuse Removal

From Equispectives (2026), Census 2022 records that approximately 82 % of households in the Merafong City LM have their refuse removed at least once a week by the local authority or a private contractor, up from approximately 74 % in 2011 and just over 79 % in 2016, although this remains the lowest of the municipalities in the West Rand District. Figure 3.45 shows that removal exceeds 90 % in Ward 11 and Ward 23, while in Ward 22 only about 55 % of households receive regular collection, and many rely on their own refuse dumps or communal disposal sites; expanding consistent waste removal in peripheral areas remains a local service delivery priority.

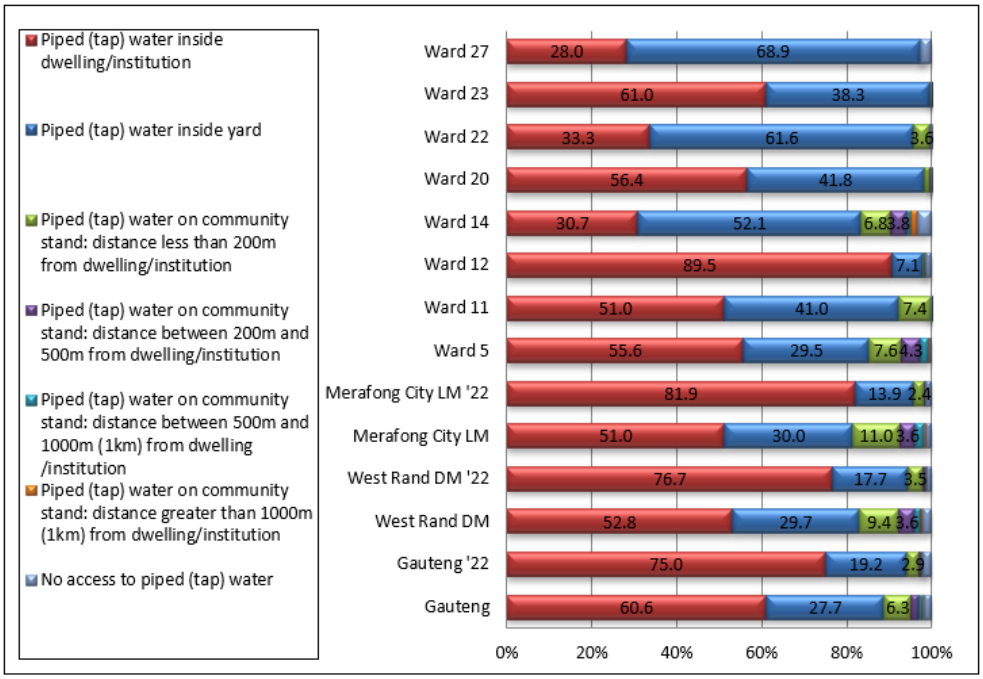


Figure 3.44 Piped water (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

3.7.6.5 Energy Source

According to Equispectives (2026), Census 2022 records that electricity is now almost universal as a lighting source in the Merafong City LM, with approximately 98% of households using electricity for lighting, up from 82.8% in 2011; all municipalities in the West Rand District are now above 90%. The 2022 Census records that approximately 72% of households in the Merafong City LM use electricity for cooking (see Figure 3.46). Paraffin remains in limited use (about 2 to 5% of households), particularly in Ward 22 and Ward 23. The use of gas for cooking has increased since 2011, particularly in urbanised wards such as Ward 14. Access to electricity for heating purposes is high, though affordability challenges persist for lower-income households.

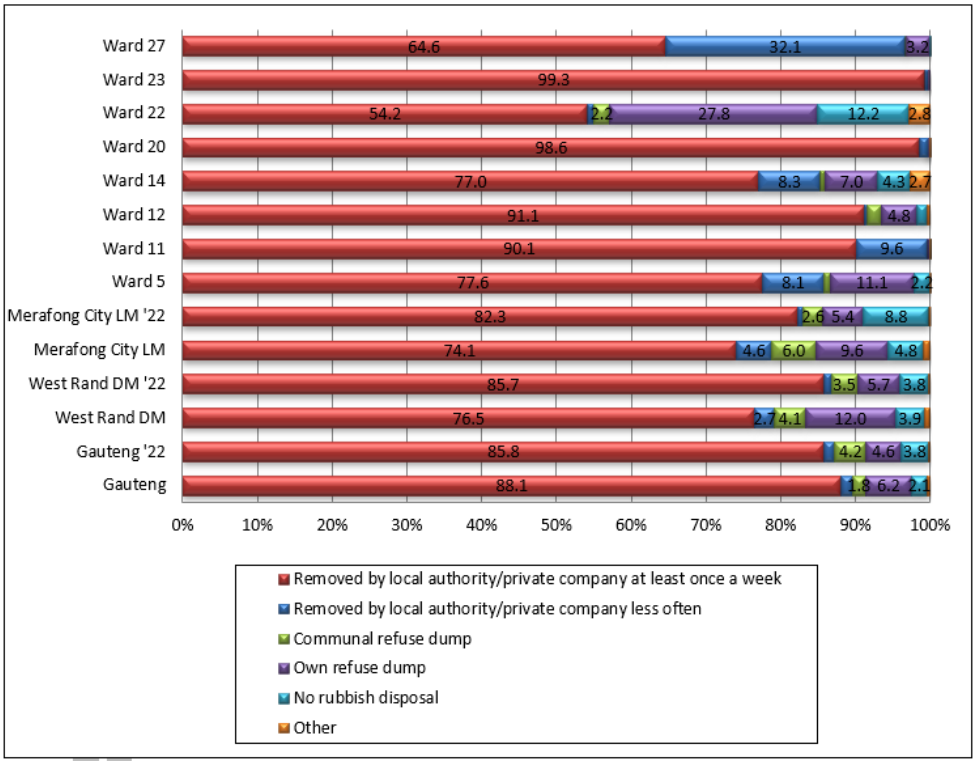


Figure 3.45 Refuse removal (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

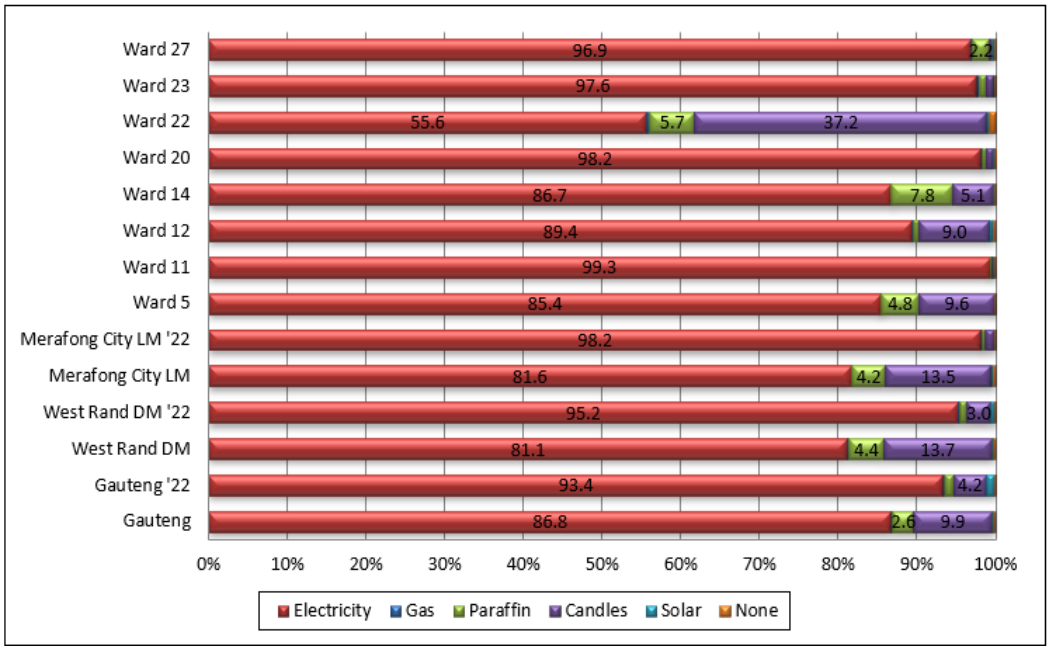


Figure 3.46 Energy source for lighting (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

Fieldwork undertaken for Equispectives (2026) records that the loss of electricity supply can be e severe and prolonged. Deelkraal Village had been without a mains electricity supply for several months at the time of the fieldwork, following the power being switched off, the plundering and burning of the local power station, and the theft of power-line towers. The theft of Eskom infrastructure was also reported by farmers and smallholders in the surrounding area.

3.7.6.6 Sanitation

According to Equispectives (2026), Census 2022 records that 93% of households in the Merafong City LM are connected to a flush toilet linked to a sewerage system, which is above the national average and higher than in 2011 (78.3%). Wards 11 and 23 show near-universal coverage (above 95 %), while Ward 22 records the lowest rate (around 79 %) and a higher use of pit toilets and bucket systems. The share of households without any sanitation facility has declined to less than 0.5 %. This reflects significant progress in sanitation provision, though informal settlements remain pockets of vulnerability.

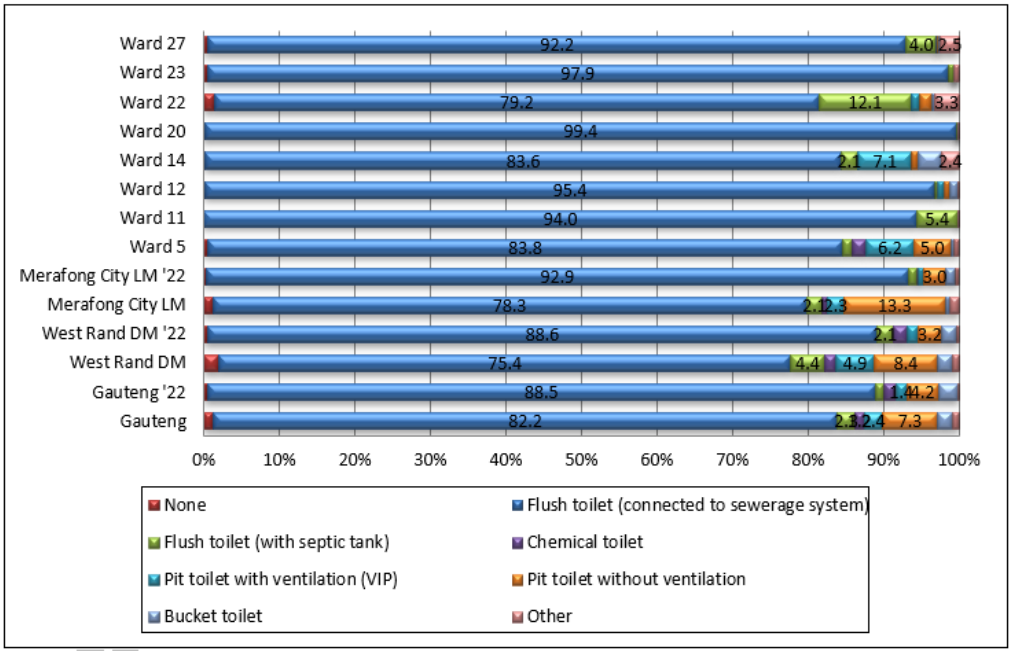


Figure 3.47 Sanitation (shown in percentage, source: Census 2011, Census 2022) (Equispectives, 2026).

AquiSim (2023) mentioned that in 2016, more than half of households in Merafong City LM (63.3 %) reported that the main toilet facility is in the dwelling, while 34.2 % reported that it is in the yard. Just over a third (39.0 %) of households report sharing their toilet facilities with other households. About three-quarters (75.4 %) of households maintain their own toilet facilities, while the municipality maintains the facilities for 15.3 % of households. Fewer than two-thirds (60.8 %) of households rated the overall quality of toilet/sanitation services as good in the Community Survey 2016.

3.7.7 Human Behavioural Characteristics

3.7.7.1 Daily Activities and Time Spent Outside

According to AquiSim (2023), many residents of Wedela and Elandsrand are employed at the mines and thus spend a large proportion of their day at work. In both areas, there is a community work programme that allows participating residents to spend up to 8 hours a day outdoors, at least 2 days a week, cleaning streets or working in local vegetable gardens. In Wedela, small children often play outside during the day. Older girls may play netball, while boys will practise sports. Some youths and some mothers just sit outside, doing nothing in particular. The incidence of people spending time outside is unknown, but when driving through the town, people were observed outdoors throughout. Residents also reported that people spend more time outside at weekends. In Elandsrand, teenagers are reported to spend most of their time indoors reading and doing homework, while younger children play outside (AquiSim, 2023).

AquiSim (2023) mentions that the large proportion of retirees living in the Deelkraal Estate means that people are at home during the day. Consequently, several people can be observed outside during the day. The Deelkraal recreational area next to the Deelkraal Dam includes a play area with outdoor equipment for children. Around the Dam, there are braai facilities. Some people fish in the Dam on a catch-and-release basis, and occasionally some of the boys swim there.

In agricultural areas, farmers and farm workers spend the entire day outdoors, engaged in farming activities. The farmers' wives spend less time outside. They mostly do gardening when they are outside. The family members who do not reside on the farm are mostly there on weekends. On weekends, some people will engage in activities such as horseback riding, bicycle riding and hiking (AquiSim, 2023).

3.7.7.2 Eating Habits

AquiSim (2023) mentions that food consumption is largely based on personal preferences and beliefs and varies not only between households in an area but also within a household. Affordability influences the types and quantities of food consumed. Residents in the study area have not been interviewed to assess their food consumption, and the discussion in this section is based on trends identified in similar studies elsewhere.

In higher-income households, residents tend to source almost all their food from formal stores such as supermarket chains, greengrocers, or butcheries that must meet certain legal standards to operate. In areas with high levels of poverty, households tend to buy from informal stores or from someone in the area who farms a specific product, such as vegetables, poultry, eggs, or milk, or they grow their own food in a garden. In some communities, access to water or its availability poses a barrier to maintaining a food garden. In some instances, access to land can also be a challenge.

Households in high-income areas tend to consume a greater variety of food products and include processed foods to a greater extent (based on personal preferences). Households living in poverty tend to have meals that undergo little processing. Bread and/or pap (maize-meal porridge) are staples, usually eaten with vegetables such as tomatoes, onions, spinach, or cabbage. Potatoes and beans are also consumed often in some households. Meat is included based on income; it is usually chicken, with red meat consumed on special occasions. Some households can only afford chicken once a week or less. Households living in poverty often lack access to a fridge and must choose foods that do not require refrigeration; any meat must be consumed as soon as possible.

Food preparation depends on the dish being prepared and the available facilities. Households that use paraffin, wood or coal tend to cook outside in a designated area.

The volume of food consumed depends on personal preferences and the means available to buy food. According to AquiSim (2023), the Community Survey 2016 indicates that 25.3 % of people in Merafong City LM ran out of money to buy food during the preceding 12 months, and 61.6 % of those who did so did so for five or more days during the preceding 30 days. Approximately 11.8% of the population in Merafong City LM reported skipping a meal in the preceding 12 months, and 63.5% skipped a meal on 5 or more days in the preceding 30 days.

3.7.7.3 Agricultural Activities

According to AquiSim (2023), some households in urban areas engage in agricultural activities. Some do so only for enjoyment, while others do so as a livelihood strategy. Census 2011 included questions on agricultural activities, such as whether the household engaged in agriculture, the types of agricultural activities, and the number of livestock or poultry kept. The data available in the public domain appears to

contain errors, and the totals do not match those published in a Stats SA publication on Agricultural Households (at the provincial level) using Census 2011 data. The data appears to significantly underreport agricultural activities, and logic checks across questions do not hold up. For this reason, the 2011 Census data on agriculture are not used in this report.

Similar studies conducted elsewhere show that urban households in areas with high poverty are more likely to engage in agricultural activities, especially when located close to open land, which is often found in mining areas or around tailings facilities. The agricultural activity with the highest incidence in these areas is food gardening, which consists mostly of growing vegetables such as spinach, cabbage, onions, tomatoes, beetroot, carrots, potatoes, beans, maize and pumpkin. In many township areas, there are many fruit trees, mainly peach and apricot, that were planted some years ago as part of a government project, and this may be the case in some of these areas as well. Food gardens are mainly grown in backyards, but those living on the edge of open space will often use this area to grow vegetables or crops on a larger scale. Cattle or goats are usually kept on the edges of open spaces as well. Most schools in areas with high poverty levels have gardens to provide learners with some food. Fruit trees provided by the Department of Agriculture were planted in the community several years ago. Fruit trees observed in 2011 include peach, apricot, plum, lemon, orange, pecan, pear and grape. Prickly pears were growing in the hilly areas.

In 2011, commercial farmers planted crops for cattle feed, while one farmer maintained a large vegetable garden that supplied the area with vegetables.

Some residents keep chickens, and cattle were observed grazing on the periphery of urban areas in 2011. Commercial farmers mostly kept cattle, with a few sheep and some chickens observed. On the game farms, there were eland, oryx, kudu, ostriches, blesbok, waterbuck, nyala, impala, and blue wildebeest.

According to the 2016 Community Survey reported by AquiSim (2023), 8.1 % of households in Merafong City LM were engaged in agriculture. Although the 2016 Community Survey asked where households conducted their agricultural activities (farmland, communal land, backyard, etc.) and what the main purpose of the activity was, this data was not released to the public. A smaller proportion of households (2.2%) reported owning poultry or livestock.

Households in the municipal area have reported involvement in agricultural activities, as shown in Table 3.20. In terms of the type of farm practice for crop farming, 22.2 % of households in Merafong City LM that farm with crops have indicated in Community Survey 2016 that they use irrigation, 34.7 % use dryland, and 43.1 % use both irrigation and dryland.

Table 3.20 Agricultural activities (households, source: Community Survey 2016) (AquiSim, 2023).

Agricultural activity	West Rand DM	Merafong City LM
Vegetable production	3.82	5.34
Grains and food crops (e.g., maize, wheat, beans, sorghum, millet, groundnuts)	0.72	1.02
Livestock production (e.g., cattle, goats, sheep, pigs)	1.01	1.25
Poultry production (e.g., chickens, ducks, geese, guinea fowl, ostrich)	1.50	1.76
Fruit production	0.59	0.58
Industrial crops (e.g., tea, coffee, cotton, tobacco)	0.04	-
Other	0.26	0.09

3.7.7.4 Food Production and Livestock

According to AquiSim (2023), home cultivation of fruit and vegetables occurs in the Wedela, Elandsrand and Deelkraal residential areas. Elandsrand has the lowest incidence of home vegetable gardens. The main obstacles are monkeys stealing the vegetables and a lack of available space. The nursery school in Elandsrand has a vegetable garden on the premises, and vegetables are used to feed the children attending the school (see Figure 3.48).



Figure 3.48 Vegetable garden of a nursery school in Elandsrand (AquiSim, 2023).

In Wedela, the incidence of home vegetable gardens is higher than in Elandsrand. One objective of the community work programme is to encourage home gardens. However, community gardens and vegetable gardens have also been established in primary schools, clinics, and home-based care centres. Fruit trees (peach, apricot and grape) provided by the Department of Agriculture have been planted in the community. It can be anticipated that there will be an increase in home gardens in the area if the project is successful.

There is a community agricultural project outside Wedela near the Kusasalethu TSF. The project is currently not active, but according to community work programme coordinators, it will become active in the future. The plans for the farm include cultivating seasonal vegetables, raising chickens and pigs, and producing honey. Cattle are currently grazing on the farm.

Produce cultivated in Wedela, Elandsrand and Deelkraal home gardens (see Figure 3.49) includes leafy and root vegetables (beetroot, carrots, onions, potatoes, lettuce, cabbage and spinach) as well as pumpkin, legumes (beans), maize, peppers and eggplant. Fruits cultivated include peaches, apricots, strawberries, prickly pears, citrus, and grapes. In agricultural areas, farmers plant crops to feed their livestock (lucerne, teff, or sorghum). Some farms have large vegetable gardens (see Figure 3.50) that sell vegetables to area residents. His farm has not been included in this report.

Vegetables grown in gardens on the farms include pumpkin, maize, beans, tomatoes, potatoes, leafy vegetables (marogo, cabbage, and spinach), root vegetables (beetroot, onions, and carrots), sugar cane and sweet potatoes. Fruit trees include pecans, plums, peaches, pears, and apples. Prickly pears are grown in the hills.

Livestock is present in all formal residential areas and on farms. In Wedela and Elandsrand, some residents keep chickens, and cattle are grazed on the outskirts of the residential areas. Residents of the Deelkraal Estate do not keep cattle, but cattle from neighbouring areas come to graze in the vicinity. Some people keep chickens and geese.



Figure 3.49 Vegetable gardens in Deelkraal Estate (AquiSim, 2023).



Figure 3.50 Vegetable garden on a Deelkraal farm (AquiSim, 2023).

All the farmers that were interviewed keep cattle (see Figure 3.51) for milk or meat. The cattle are sold at one of the local feedlots, or slaughtered at the abattoir in Potchefstroom or Syferfontein. The farmers (5 in total) that were interviewed had a combined total of about 346 cattle. Some farmers keep sheep (see Figure 3.51), with a minimum of 93 sheep per area. Sheep are mostly slaughtered and processed on farms. Chickens, geese and ducks are present on some farms.



Figure 3.51 Examples of livestock farming on the Deelkraal farms (AquiSim, 2023).

3.7.7.5 Vulnerability

Two broad criteria, namely proximity and level of vulnerability, were used to screen areas surrounding mining activities for human behaviour. Proximity to the mining activities assumes that people who are closest to the mine, as well as the most vulnerable groups closest to the mine, have the greatest risk of exposure, and if their exposure is at an acceptable level, so will be the level of exposure of those further away from the mine or belonging to less vulnerable groups. Households within a 5 km radius of the mining activities were included. Households who live in poverty and are deprived are at a much greater risk of exposure through the dwellings they reside in, services they have access to, food and water sources, etc and as such have a higher level of vulnerability. Children, the aged and people in poor health are also considered vulnerable.

Based on the indicators used in the South African Multidimensional Poverty Index (SAMPI) (Statistics South Africa, 2014), a list of indicators was compiled, and an average score was calculated for each ward to determine its vulnerability level. Ward-level indicators are derived from Census 2011 and mapped to the

2016 ward delineation, as Census 2022 results have been released only at the municipal level and not at the ward level (Equispectives, 2026). Municipal-level figures quoted elsewhere in this section are from Census 2022. Some indicators were added as they were deemed important for the project. The lower the average score, the greater the ward's vulnerability. The following indicators were used:

- Education – persons aged 20 years or older who have not completed high school.
- The energy source for lighting – households using paraffin, candles, wood, other or nothing.
- The energy source for heating – households using paraffin, wood, coal, dung, other, or nothing.
- The energy source for cooking – households using paraffin, wood, coal, dung, other, or nothing.
- Access to water – no piped water in a dwelling or stand.
- Water source – not a regional or local water scheme (borehole, spring, river, stream, dam, water tank, vendor, etc).
- Sanitation – no flushing toilet.
- Unemployment – adults who are unemployed and discouraged work-seekers.
- Those not economically active (as they are likely to spend more time outside).
- Child-headed households – households headed by children aged 10-19 years.
- Aged heads of household – households with heads aged 65 years and older.

Table 3.21 shows the proportions of households or persons in each ward that meet the criteria for each indicator, while Figure 3.52 shows the location of the most vulnerable communities near the Project.

Table 3.21 Vulnerability indicators (source: Census 2011, shown in percentage) (AquiSim, 2023).

Vulnerability Indicator	West Rand	Merafong City	Ward 11	Ward 12	Ward 20	Ward 22	Ward 23
Education	58.69	66.29	69.33	53.83	69.92	77.21	67.40
Lighting	18.64	18.17	0.50	10.18	1.62	44.07	2.28
Heating	28.17	33.34	6.49	14.90	46.82	59.81	60.66
Cooking	19.81	24.37	0.91	9.61	21.37	49.21	25.15
Access water	17.45	19.02	8.01	3.32	1.84	5.06	0.64
Water source	11.55	7.74	1.37	4.94	2.46	23.15	0.85
Sanitation	20.21	19.67	0.59	4.31	0.40	8.63	1.37
Dwelling type	25.33	21.28	0.43	1.21	9.77	37.84	21.86
Unemployment	21.09	20.84	9.74	10.17	31.94	20.99	24.01
Not economically active	29.19	32.66	19.65	44.68	23.70	44.77	29.16
Child-headed household	0.88	0.99	0.39	0.33	1.05	1.37	1.19
Retired headed household	7.48	6.38	1.10	9.70	1.80	8.92	2.64

The most vulnerable ward in the study area according to the ward-level indicators is Ward 22. This ward consists mostly of farms and smallholdings, but also includes part of Kokosi, which is considered the most vulnerable area in the ward. Kokosi is approximately 10 km from the Elandsrand TSF. Ward 23 is the second-most vulnerable area and comprises the portion of Wedela closest to the Mponeng TSF. Ward-level dependency ratios support this ranking: Ward 22 records the highest total dependency ratio in the study area (50.89), followed by Ward 20 (40.04), Ward 12 (39.12), and Ward 23 (37.18), compared with a municipal figure of 40.95 in 2022 (Equispectives, 2026).

Equispectives (2026) identifies the following groups within the project area of influence as vulnerable or disadvantaged, and these should be read together with the ward-level indicators above: elderly and infirm residents of Deelkraal Village, including persons dependent on oxygen and reliant on a supply of electricity that has been interrupted for an extended period; households in Deelkraal Village affected by the loss of electricity, the consequent failure of sewage pumping and dependence on water tankering; informal occupiers and artisanal miners on and near the proposed footprint, who are reported to be largely illiterate with limited English, hold no formal tenure and depend on the only cattle kraal in the immediate area; farm workers and smallholders whose livestock and domestic water supply depend on an on-farm dam and stream; unemployed and grant-dependent households across the surrounding settlements; and women and youth, who are disproportionately represented in informal and precarious work.

3.7.8 Summary

The major change in the area was Harmony Gold's acquisition of the neighbouring Mponeng Mine and its remaining assets in 2020. AngloGold Ashanti undertook extensive restructuring of its operations in 2016 and 2018, and as a result, some of the mining residences in the area are now unoccupied. Downscaling in the gold mining industry has resulted in greater unemployment and increased poverty in the area, and, in general, community groups are more vulnerable than before; the COVID-19 pandemic also contributed to this vulnerability. Nationally, the contraction has slowed rather than reversed: direct employment in gold mining declined by approximately 1.2 % between 2022 and 2023 and by 0.9 % relative to pre-COVID (2019) levels, but the socio-economic consequences of the earlier large-scale retrenchments remain visible in the mine-linked settlements of Blyvooruitzicht, Wedela and Deelkraal (Equispectives, 2026).

Fieldwork undertaken for Equispectives (2026) records a receiving environment under significant social and economic stress. Very high local unemployment, widespread dependence on social grants, deteriorating municipal services and roads, substance abuse and crime (including drug dealing, stock theft and the theft of Eskom infrastructure), insecure tenure and the absence of title deeds for some occupiers, and mistrust of both the municipality and mining operators are recurring features of the area. Deelkraal Village has been without a mains electricity supply for several months following the plundering and burning of the local power station and the theft of power-line towers, resulting in sewage no longer being pumped and the village relying on water tankering. A small settlement of informal occupiers and artisanal miners (zama-zamas), keeping between 200 and 400 cattle, as well as goats, pigs, and poultry, and cultivating crops, is present on and adjacent to the proposed tailings storage facility footprint. Artisanal mining and infrastructure theft are pervasive features of the operating environment (Equispectives, 2026).

Census 2022 and the Draft Integrated Development Plan for Merafong City 2025/26 confirm these trends: while the population and number of households in the municipal area have continued to grow, poverty levels remain high (approximately 53.1 % living below the upper-bound poverty line in 2020) and mining's contribution to the regional economy continues to decline, although access to basic services (formal housing, piped water, electricity and sanitation) improved measurably between 2011 and 2022 (EIMS, 2026).

Table 3.22 summarises the socio-economic, demographic, and human behavioural data for the area surrounding the Project, updated from Equispectives (2026) and supplemented at the ward level with Census 2011 data mapped to the 2016 ward delineation (AquiSim, 2023).

Table 3.22 Summary of the socio-economic, demographic and human behavioural data for the area near the Project (AquiSim, 2023; Equispectives, 2026)

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
Location	Wedela; Deelkraal; Elandsridge (Elandsrand)	No informal sections, but some of the RDP houses in Wedela have shacks in their yards.	Farms and large and small holdings in the area around Deelkraal. There do not seem to be any major farming activities in the immediate vicinity.	Wedela
Population distribution	In Wedela, almost all residents are Black. Elandsridge has a mixed population, with the majority being Black. Deelkraal has a mixed population.	Almost all are from the Black population	Most farmers are White, although there are Black farmers in the area. Farm workers are from the Black population	From the Black population
Family structure	Not known for all the areas, but most likely mostly nuclear families in Elandsridge and Deelkraal, with a mix of family structures in Wedela.	Not known, but most likely a mix of family structures.	Mainly nuclear families	n/a
Community activities	Deelkraal: Some people are observed outside during the day. There is a dam with braai facilities and a play area where people can spend time over weekends. Some people fish, and occasionally some boys will swim in the dam Wedela: time spent outside depends on individual circumstances. Those who are at home during the day do chores indoors, garden, fetch wood, cook outside, or spend time socialising outside. Some people hunt, and some religious activities take place outside Elandsridge: Younger children seem to spend a lot of time outside playing.	Information not available	Farming activities On weekends, horseback riding, bicycle riding, hiking, etc.	As per the area where they live
Access to water	Piped municipal water inside the yard or dwelling. Animals in Wedela drink water from a stream.	Not known, but most likely piped municipal water inside the yard for most dwellings.	Boreholes and the use of dams and rivers for irrigating crops were available.	Municipal water or rainwater is used. Water affordability is an issue.
Energy sources	Mainly electricity. Some residents cook on gas or wood.	Not known. The RDP houses may have electricity, and they may be connected to the backyard shacks. Likely to be a high incidence of use of paraffin and candles due to the high cost of electricity.	Electricity. Some use gas for cooking and wood for heating. Some are in the process of converting to solar. Farmworkers use electricity, candles, paraffin and wood.	Depending on the area where they live.
Refuse removal	Removed weekly. In Wedela, there are rubbish heaps on the outskirts of the township.	Municipal services are weekly in Wedela. There are rubbish heaps in the streets – some seem to burn their refuse.	Most remove refuse to landfills. Some burn and bury. Recycling is taking place, e.g., a compost heap.	Depending on the area where they live.
Sanitation	Mostly flush toilets connected to a sewerage system.	Not known. Most of the RDP houses seem to have a toilet, either inside or outside, but it is not known whether this facility is available to those living in zinc structures in the yard.	Flush toilets are connected to a septic tank.	Depending on the area where they live.

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
Dwellings	In Elandsridge, the houses are brick structures. Many houses seem to have "servant's quarters" on the outside, which in some cases seem to be rented out. Houses have separate yards. Houses in Deelkraal are brick structures with separate yards. Mostly 3-4 bedrooms with live-in quarters for a domestic worker There are different types of houses in Wedela – RDP houses, bank houses, and mine houses. The houses span a wide range of incomes—all brick structures.	Informal structures – mostly made from zinc.	Brick structures. In most cases, zinc roofs.	n/a
Source of food	Local shops or shops in town. Those who grow vegetables consume these when available.	As for Wedela.	Most shops in town. Milk is mainly sourced from the farm and, in many instances, meat as well. When available, vegetables are sourced from a neighbouring farm or their own farm, but quite often bought in town.	This depends on the area where they live.
Food production	The highest incidence of vegetable gardens is in Wedela. Leafy vegetables: spinach, lettuce, cabbage, wild spinach. Root vegetables: turnips, carrots, spring onions, beetroot, onions. Other vegetables: okra, peas, maize, tomatoes, beans, pumpkin, peppers, eggplant. Fruit: peaches, apricots, grapes, plums, lemons, oranges, prickly pears. Deelkraal: some vegetable gardens, but the incidence is fairly low. Elandsridge: low incidence of own vegetable gardens (monkeys steal vegetables).	As for Wedela.	Feed for livestock: lucerne, teff, and sorghum. Leafy vegetables – marogo, cabbage and spinach Root vegetables – beetroot, onion, carrots Other vegetables – pumpkin, maize, beans, tomatoes, potatoes, sweet potatoes and sugar cane. Fruit – pecan nuts, plum, peach, pear, apple, prickly pear. Farm workers – beans, pumpkin, spinach, tomatoes, onions and carrots.	Fruit – peach and apricot Leafy vegetables – cabbage and spinach Root vegetables – potatoes, beetroot, carrots, onions, and sweet potatoes. Other vegetables – maize, pumpkin and beans.
Categories of food (originating from a local source)	Depends on personal preferences – greater variety in higher-income areas In areas with high poverty, less variety - mostly pap or bread with vegetables, and chicken for those that can afford it.	Depends on personal preferences – greater variety in higher-income areas.	Depends on personal preferences – greater variety in higher-income areas.	As per the area where they live.
Food preparation	A variety of methods are used.	A variety of methods are used.	A variety of methods are used.	As per the area where they live.
Volume of food	Depends on personal preference In lower-income areas, it also depends on availability.	Depends on the availability of money – many cannot afford three meals a day.	Depends on personal preference.	As per the area where they live.
Livestock	Wedela: Some households keep chickens. Livestock (cattle, sheep, and goats) are kept along the perimeter of Wedela. Deelkraal: chicken, geese. Pig observed. Cattle from neighbours graze in the area. Elandsridge: Some individuals keep cattle in open spaces.	As for Wedela.	Mainly cattle. Some keep sheep or chickens. Horses. Game. Exotic birds.	Cattle on community farm project. Chickens and piggery are planned.
Social infrastructure	Wedela: Schools, clinics, open spaces and shops.	Same infrastructure as for the rest of Wedela.	Hunting. Guest accommodation.	n/a

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
	Elandsridge: Pre-school, shop, open spaces. Deelkraal: Nursery school, clinic, supermarket, liquor store, recreational hall, recreational area, braai facilities, sports fields (some planned for reinstatement).		Game viewing.	
Socio-economic status	Mixed socio-economic status.	Not known, but people in this area are likely to be poor and have high unemployment.	All the farmers are employed and able to make a living.	As per the area where they live.

3.8 Radiological Conditions

3.8.1 General

The purpose of this section is to provide an overview of the radiological conditions associated with the Project area. Despite the historical nature of the associated facilities and activities, little historical data is available for the Project area. Therefore, the objective is to present the latest available data for the Project from AquiSim (2023), including full-spectrum radioanalytical results for the ore, waste rock, tailings material, and the upcast ventilation shafts. Additional surface water and groundwater analyses, as well as sediment, dust fallout, and fish radioanalytical results, were performed at the Necsa Radioanalytical Laboratory at Pelindaba and are also available.

All the existing TSFs associated with the Kusasalethu Operations were sampled for full-spectrum analysis. In addition to these TSFs, Figure 3.53 shows the locations of surface water and groundwater sampling points.

3.8.2 Radioactivity Associated with Raw Materials, Products and Residues

3.8.2.1 Ore

A sample of ore from the former Deelkraal mine was submitted to the Radioanalysis Laboratory of the South African Nuclear Energy Corporation (Necsa) as part of an earlier radiological study conducted for the Deelkraal and Elandsrand mines. The ore sample is described in the laboratory report as Deelkraal G.R. Table 3.23 summarises the nuclide-specific activity concentrations reported for the sample. The radioanalytical data presented in Table 3.23 are considered representative of the gold-bearing ore that was processed and handled at the Kusasalethu Operations in 2001.

3.8.2.2 Waste Rock Material

Two historical waste rock dumps are associated with the Kusasalethu Operations. However, the Kusasalethu Operations received an exemption from the NNR for both these facilities, under which the material can be reprocessed and used for industrial applications (e.g., road construction). The Deelkraal WRD has been reprocessed, leaving only the unrehabilitated footprint, with some residual material. Stone and Allied are processing the Kusasalethu WRD for road construction material. For completeness, all available results (including historical results) are reported here.

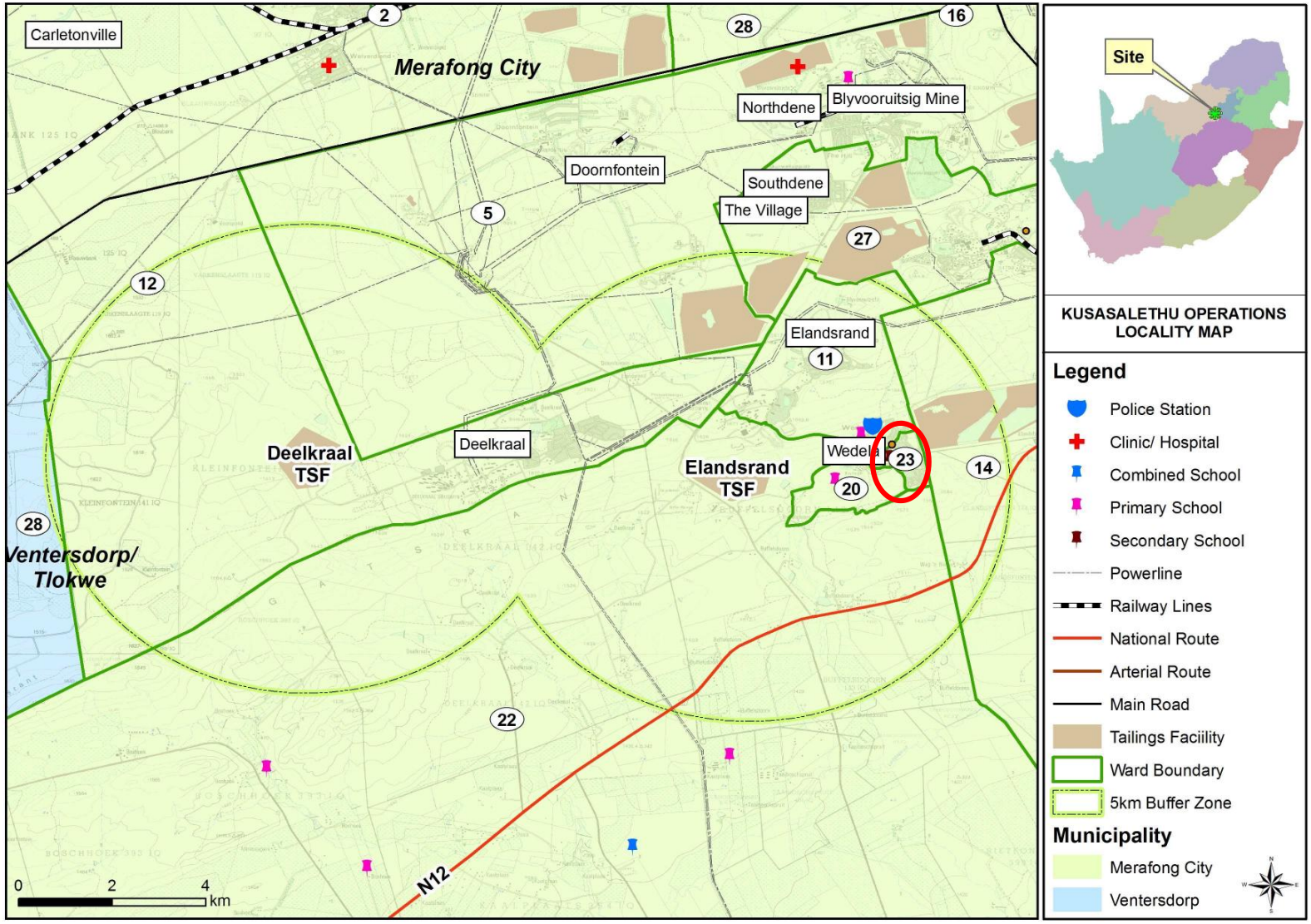


Figure 3.52 Locality map showing the most vulnerable community near the Project (AquiSim, 2023).

Table 3.23 Radionuclide Content of Ore Sample (Necsa Report No. RA-03957 dated 10 December 2001).

Radionuclide	Sample Activity	Uncertainty
	Bq.kg^{-1}	
U-238	772	8
Ra-226	798	40
Pb-210	714	53
U-235	35.6	0.4
Th-232	57.7	2.4
Ra-228	<140	-
Th-228	65.5	8.2
Gross α	6,610	310
Gross β	7,930	90

Table 3.24 and Table 3.25 present the full-spectrum radioanalysis results for the Deelkraal and Kusasalethu WRDs, respectively. The results for the Deelkraal WRD, which has been reprocessed, span from 2008 to 2017, while the results for the Kusasalethu WRD, which is still being processed, span from 2012 to 2022.

Table 3.24 Full-spectrum radioanalysis results available for the Deelkraal WRD (2008 to 2017).

Sampling Date	19/05/2008	21/02/2014	21/02/2014	21/02/2014	21/02/2014	21/02/2014	09/06/2017
Necsa Report No.	RA-08868	RA-15483x1	RA-15483x2	RA-15483x3	RA-15483x4	RA-15483x5	RS2017-2547
Radionuclide	Activity Concentration (Bq.kg^{-1})						
U-238	35	15.6	223	24	23.8	16.1	80.7
U-234	35.3	15.7	225	24.2	24	16.2	81.4
Ra-226	43.8	16	231	22.5	22.8	13.3	92
Pb-210	75.5	< 86	294	< 84	< 93	< 86	136
U-235	1.61	0.716	10.3	1.1	1.1	0.739	3.72
Th-232	12.9	9.25	23.7	14	11.7	8.76	14.2
Ra-228	15.3	5.5	17.5	11.8	< 19	< 18	< MDA (26)
Th-228	18	12	18	12.9	12	11	9.9
Gross α	544	1100	2640	610	300	335	210
Gross β	545	348	1020	472	567	533	476

Table 3.25 Full-spectrum radioanalysis results available for the Kusasalethu WRD (2012 to 2022).

Sampling Date	30/11/2012	09/06/2017	14/08/2018	18/10/2019	09/07/2020	13/04/2021	08/02/2022
Necsa Report No.	RA-13851	RS2017-2547	RS2018-3865	RS2019-4988	RS2020-2569	RS2021-1458	RS2022-0351
Radionuclide	Activity Concentration (Bq.kg^{-1})						
U-238	30.6	31.4	20.6	18	12.8	10.9	13.8
U-234	30.9	31.6	20.8	18.2	12.9	11	13.9
Ra-226	29.7	35.3	16.6	17.2	< MDA (22)	12	< MDA (33)
Pb-210	<83	< MDA (120)	< MDA (56)	< MDA (59)	< MDA (64)		< MDA (83)
U-235	1.41	1.44	0.949	0.83	0.591	0.503	0.637
Th-232	12.1	12.5	10.4	14.7	9.57	8.8	9.09
Ra-228	15	11	16.2	< MDA (12)	< MDA (68)	< MDA	< MDA (71)
Th-228	21.4	8.4	18.5	8.4	< MDA (88)	12	< MDA (97)
Gross α	415	< MDA (560)	43	70	< MDA (530)	< MDA	< MDA (1600)
Gross β	694	559	570	547	638	618	529

3.8.2.3 Tailings Material

Two tailings storage facilities are associated with the Kusasalethu Operations. The Deelkraal TSF is dormant, and no additional tailings material is deposited at the facility. The Kusasalethu TSF is operational and receives tailings material at a rate of 60 ktpm.

Table 3.26 and Table 3.27 present the full-spectrum radioanalysis results for the Deelkraal TSF and Kusasalethu TSF, respectively. The results represent tailings material generated from 2010 to 2020.

Table 3.26 Full-spectrum radioanalysis results available for the Deelkraal TSF (2010 to 2020).

Sampling Date	14/04/2010	14/04/2010	23/01/2013	23/01/2013	06/10/2020
Necsa Report No.	RJ2010-0336	RJ2010-0336	RA-13961	RA-13961	RS2020-3133
Sampling Point	Deelkraal (0-1 m)	Deelkraal (1-2 m)	Deelkraal: 1m	Deelkraal: 2m	Deelkraal TSF
Radionuclide	Activity Concentration ($Bq.kg^{-1}$)				
U-238	333	423	231	193	707
U-234	336	427	233	194	713
Ra-226	456	582	535	291	861
Pb-210	538	925	616	333	1000
U-235	15.3	19.5	10.6	8.87	32.6
Th-232	38.2	51.1	27.3	26.1	62.9
Ra-228	54.5	42.3	40.8	40.6	67.5
Th-228	37.6	50.5	34.8	36.9	79
Gross α	4110	5960	4500	2700	7620
Gross β	1900	2260	1970	1380	4050

Table 3.27 Full-spectrum radioanalysis results available for the Kusasalethu TSF (2010 to 2020).

Sampling Date	14/04/2010	14/04/2010	23/01/2013	23/01/2013	11/12/2014	06/10/2020
Necsa Report No.	RJ2010-0336	RJ2010-0336	RA-13961	RA-13961	RS2014-0726	RS2020-3133
Sampling Point	Kusasalethu TSF (0-1 m)	Kusasalethu TSF (1-2 m)	Kusasalethu TSF (1m)	Kusasalethu TSF (2m)	Kusasalethu TSF	Kusasalethu TSF
Radionuclide	Activity Concentration ($Bq.kg^{-1}$)					
U-238	653	552	494	437	333	435
U-234	659	556	498	441		438
Ra-226	661	626	475	474	322	545
Pb-210	703	747	673	503	369	518
U-235	30.1	25.4	22.7	20.1	15.3	20
Th-232	48.3	45.4	31.6	28.4	29.9	40.4
Ra-228	43.4	63.1	39.7	25.9	<MDA	62.6
Th-228	321	48.1	42.5	41.9	32	84.9
Gross α	5760	6580	5420	4930	3280	4370
Gross β	2880	2680	2250	2250	1810	2560

Results from a radiological analysis of tailings samples collected in 2010 for both the Deelkraal TSF and Kusasalethu TSF are representative of 15 individual samples collected from each TSF, which were composited to produce two separate sets of samples for the surface zone (comprising the first metre) and the sub-surface zone (between 1 m and 2 m deep) of each TSF. The surface zone sample is taken as representative of the component that will be dispersed into the atmosphere, while the sub-surface sample is considered representative of the radioactivity expected to leach to the underlying strata (see Table 3.26 and Table 3.27).

In 2013, a similar sampling campaign was carried out at the Deelkraal TSF and Kusasalethu TSF, where samples of the surface (1m) and sub-surface (2m) zones were collected and analysed (see Table 3.26 and Table 3.27). A composite sample of the tailings material produced at the Kusasalethu gold plant was collected over thirty days in 2014 (see Table 3.27)

3.8.2.4 Up-cast Ventilation Shafts

Upcast ventilation shafts (or vent shafts) release air that has been circulated through the underground workings to the atmosphere. Associated with this air is radon gas released from underground working environments, which can expose members of the public living downwind of the release points to radiation. From this perspective, these shafts serve as point sources for atmospheric pathways (radon release).

The RGM measurements taken in the Upcast Vent Shaft at the Kusasalethu Mine are presented in Table 3.28, with those taken in the Upcast Vent Shaft at the Deelkraal Mine presented in Table 3.29.

Table 3.28 RGM Measurements taken in the Upcast Vent Shaft at the Kusasalethu Mine (January 2016 to August 2021).

Monitor	Bq.h.m^{-3}	Date In	Date Out	Duration (Hrs)	Calculated Concentration (Bq.m^{-3})
32403	6.68E+05	17-Jan-16	17-Jul-16	4392	152
32404	7.74E+05				176
32405	4.88E+05				111
Average	**6.43E+05**				**146**
78891	6.43E+05	01-Jul-16	30-Dec-16	4392	146
78892	6.58E+05				150
78893	6.37E+05				145
Average	**6.46E+05**				**147**
17779	8.70E+05	30-Dec-16	06-Aug-17	5280	165
17780	1.02E+06				193
17781	1.02E+06				193
Average	**9.70E+05**				**184**
83152	6.00E+05	14-Jan-18	08-May-18	2760	217
83153	6.29E+05				228
83154	7.61E+05				276
Average	**6.63E+05**				**240**
96129	5.26E+05	08-May-18	05-Aug-18	2160	244
96130	4.49E+05				208
96131	7.27E+05				337
Average	**5.67E+05**				**263**
96062	5.75E+05	06-Feb-20	08-Mar-20	768	749
96063	6.07E+05				791
96064	6.51E+05				847
Average	**6.11E+05**				**796**
42442	2.25E+05	23-Oct-20	08-Nov-20	408	551
42443	2.43E+05				595
42444	2.28E+05				558
Average	**2.32E+05**				**568**
56711	6.08E+05	22-Jan-21	14-Mar-21	1248	487
56712	6.47E+05				518
56713	6.26E+05				502
Average	**6.27E+05**				**502**
78905	6.71E+05	04-Jul-21	08-Aug-21	864	777
78906	7.65E+05				886
78907	7.40E+05				856
Average	**7.25E+05**				**840**

3.8.3 Environmental Monitoring

3.8.3.1 Surface Water

The available surface water monitoring results date back to 2010, when a comprehensive surface water sampling campaign was conducted to determine the potential radiological impact of the operations on the surface water environment. A total of 14 points were identified for full-spectrum radioanalysis. These

locations are marked on the map in Figure 3.53, and Table 3.30 presents the coordinates and a description of the sampling locations. Table 3.31 summarises the full-spectrum radioanalysis results for the 14 samples.

Table 3.29 RGM Measurements taken in the Upcast Vent Shaft at the Deelkraal mine (February 2016 to October 2021).

Monitor	Bq.h.m^{-3}	Date In	Date Out	Duration (Hrs)	Calculated Concentration (Bq.m^{-3})
32400	5.33E+06	21-Feb-16	24-Jul-16	3720	1433
32401	4.91E+06				1320
32402	4.88E+06				1312
Average	**5.04E+06**				**1355**
78888	6.11E+06	24-Jul-16	25-Jan-17	4464	1369
78889	1.03E+07				2307
78890	9.64E+06				2159
Average	**8.68E+06**				**1945**
17776	2.33E+06	25-Jan-17	29-Nov-17	7416	314
17777	1.91E+06				258
17778	1.97E+06				266
Average	**2.07E+06**				**279**
55859	3.50E+05	22-Nov-17	10-Jan-18	1200	292
55860	3.10E+05				258
55861	3.36E+05				280
Average	**3.32E+05**				**277**
96126	1.82E+06	07-May-18	05-Aug-18	2184	833
96127	1.74E+06				797
96128	9.10E+05				417
Average	**1.49E+06**				**682**
96083	1.37E+06	06-Feb-20	08-Mar-20	768	1784
96084	1.43E+06				1860
96085	1.46E+06				1900
Average	**1.42E+06**				**1848**
28862	4.07E+06	12-Jul-20	26-Aug-20	1104	3685
28863	2.97E+06				2693
28864	2.99E+06				2707
Average	**3.34E+06**				**3028**
56708	4.88E+05	22-Jan-21	14-Mar-21	1248	391
56709	5.04E+05				404
56710	4.72E+05				378
Average	**4.88E+05**				**391**
78902	4.59E+06	04-Sep-21	13-Oct-21	960	4777
78903	4.62E+06				4811
78904	4.59E+06				4783
Average	**4.60E+06**				**4790**

A less comprehensive surface water sampling campaign was conducted in 2015. A total of 4 points were identified for full-spectrum radioanalysis. These locations are shown on the map in Figure 3.53, and Table 3.30 provides the coordinates and descriptions of the sampling locations. Table 3.32 summarises the full-spectrum radioanalysis results for the 4 samples.

Table 3.30 Description of surface water sampling points for full-spectrum analysis performed in 2010 and 2015.

Sample	Latitude	Longitude	Description
Sample 1	-26.4385°S	27.3137°E	Piet se Dam stream to Wonderfontein Spruit
Sample 2	-26.4396°S	27.3202°E	Stream from Anglo Dam No. 3
Sample 3	-26.4408°S	27.3272°E	An outlet of Anglo Dam No. 3
Sample 4	-26.4558°S	27.3194°E	Deelkraal recreational dam
Sample 5	-26.4556°S	27.2757°E	Deelkraal TSF Return Water Dam
Sample 6	-26.4610°S	27.3044°E	Deelkraal WRD run off
Sample 7	-26.5022°S	27.3744°E	Wedela stream to Ensel Spruit
Sample 8	-26.4676°S	27.3668°E	Kusasalethu Return Water Dam
Sample 9	-26.4646°S	27.3649°E	Stream from Metallurgical Plant to Kusasalethu RWD
Sample 10	-26.4695°S	27.3679°E	Wedela Stream to Loop Spruit
Sample 11	-26.4446°S	27.3593°E	Inflow to Anglo Dam No. 3
Sample 12	-26.4447°S	27.3597°E	Run-off from Anglo TSF
Sample 13	-26.4448°S	27.3597°E	Kusasalethu Shaft area run-off
Sample 14	-26.4448°S	27.3595°E	Golf Course outlet
SW1	-26.4359°S	27.3672°E	Mangaan Drive
SW5	-26.4532°S	27.3177°E	Piet se Dam
SW6	-26.4603°S	27.3064°E	Waste Rock Outlet
SW7	-26.4548°S	27.2773°E	Deelkraal TSF Return Water Dam

Table 3.31 Summary of the full-spectrum analysis (RJ2010-0335, dated 20 September 2010) for 14 surface water sampling points identified for a monitoring campaign in 2010 (see Table 3.30 for description and Figure 3.53 for locations).

Sampling Date	29/03/2010	29/03/2010	29/03/2010	29/03/2010	29/03/2010	29/03/2010	29/03/2010
Sampling Point	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	609	732	727	117	4810	4690	119
U-234	568	708	714	104	4300	4180	128
Th-230	8.1	227	51.7	12	43.4	25	18.7
Ra-226	21.6	22.8	18.4	8.19	68	7.69	7.52
Pb-210							
Po-210	3	1	4.37	1.8	10.5	3.6	3
U-235	26.2	32.3	33.5	5.4	222	216	5.46
Th-227	4.33	8.82	4.93	3.5	14.1	5.1	7.6
Ra-223	5.24	3.78	9.84	-7.9	4.1	0.76	-4.4
Th-232	1.4	1.93	2.5	0.43	4.85	0.34	4.11
Th-228	0.78	4.5	5.39	3.2	7.03	1	3.7
Ra-224	<MDA	2	4.64	1.1	2.72	0.89	1.9
Gross α	790	580	570	-170	5230	3220	-6
Gross β	794	910	1020	5.2	4370	6030	260

Sampling Date	29/03/2010	29/03/2010	29/03/2010	29/03/2010	29/03/2010	29/03/2010	29/03/2010
Sampling Point	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	293	2960	6.75	191	55.2	382	194
U-234	273	2860	8.46	205	64.7	347	180
Th-230	41	21.7	11	13.9	18.8	14.1	13
Ra-226	55.3	80	0.45	68.6	2.8	162	93.4
Pb-210							
Po-210	4.75	6.61	3.39	2	4.4	0.53	2.5
U-235	13.5	144	0.311	8.78	2.54	17.6	8.56
Th-227	4.36	7.34	11.1	3.93	6.77	7.5	14.5
Ra-223	-31	-7.9	6.03	-5.9	3	-53	-36
Th-232	1.19	0.37	4.69	0.55	0.81	2.78	3.3
Th-228	6.43	4.4	3.2	4.31	13.8	5.8	-1.3
Ra-224	1.2	6.76	-1.3	2.7	2.7	2.6	4.16
Gross α	380	2680	-12	340	-89	450	130
Gross β	1260	3010	-83	537	-27	779	400

Table 3.32 Full-spectrum radioanalysis results of surface water samples collected in November 2014 (Necsa Report No. RS2014-0632-01 dated 25 March 2015).

Sampling Date	14/11/2014	14/11/2014	14/11/2014	14/11/2014
Sampling Point	SW1	SW5	SW6	SW7
Radionuclide	Activity Concentration ($mBq.L^{-1}$)			
U-238	981	633	2560	877
U-234	898	667	2280	885
Th-230	38.6	46.2	144	61.5
Ra-226	48.3	35.5	112	38
Po-210	20	9.14	62.3	60
U-235	45.2	29.1	118	44
Th-227	3.4	17.4	13	-0.52
Ra-223	4.8	-1.4	5.67	-4.2
Th-232	10.1	28.8	19	5.9
Th-228	11.3	4.4	15.2	15.5
Ra-224	4.46	<MDA	3.2	3.04
Gross α	728	841	5450	990
Gross β	2970	1410	2560	1840

Since 2011, surface water monitoring has been conducted regularly at 3 points: the Golf Course, the Deelkraal Village Dam, and the Wedela stream. Table 3.34 to Table 3.36 summarise the full spectrum radioanalysis results for the 3 monitoring points.

3.8.3.2 Sediment

Two sets of sediment samples were collected from streams influenced by the major outflows from the Project. Both sets of samples were collected in February 2012 and analysed for total uranium content. The first set was collected from the so-called Wedela stream, which flows through the township of Wedela. The sediment samples were collected from the stream bed and from dams along the stream.

Table 3.33 Summary of total uranium concentrations in stream sediments.

Sample Sets	Average	Minimum	Maximum
	$mg.kg^{-1}$		
Welverdiend Stream	18.6	1.0	87.9
Welverdiend Stream Background	2.5	1.0	6.9
Wedela Stream	2.9	1.0	7.7
Wedela Stream Dams	1.0	1.0	1.0
Wedela Stream Background	2.9	1.0	6.6

Figure 3.54 shows maps of the Welverdiend stream, with measurement locations where total uranium concentrations below and above 50 mg kg^{-1} were measured in sediment samples during the 2012 sampling campaign. In June 2012, three further sediment samples were collected from the three locations with the highest uranium concentrations for full-spectrum radioanalysis. Table 3.37 summarises the full-spectrum results for the three sediment samples.

Samples were also collected upstream of the point where water from the Kusasalethu Operations flows into the Wedela stream. These samples are marked as 'Background'. Similarly, the second set of streambed sediment samples was collected from the Welverdiend stream, which flows into the Wonderfontein Catchment to the north of the Kusasalethu Operations. Table 3.33 presents a summary of the average, minimum and maximum uranium concentrations measured in the stream sediments.

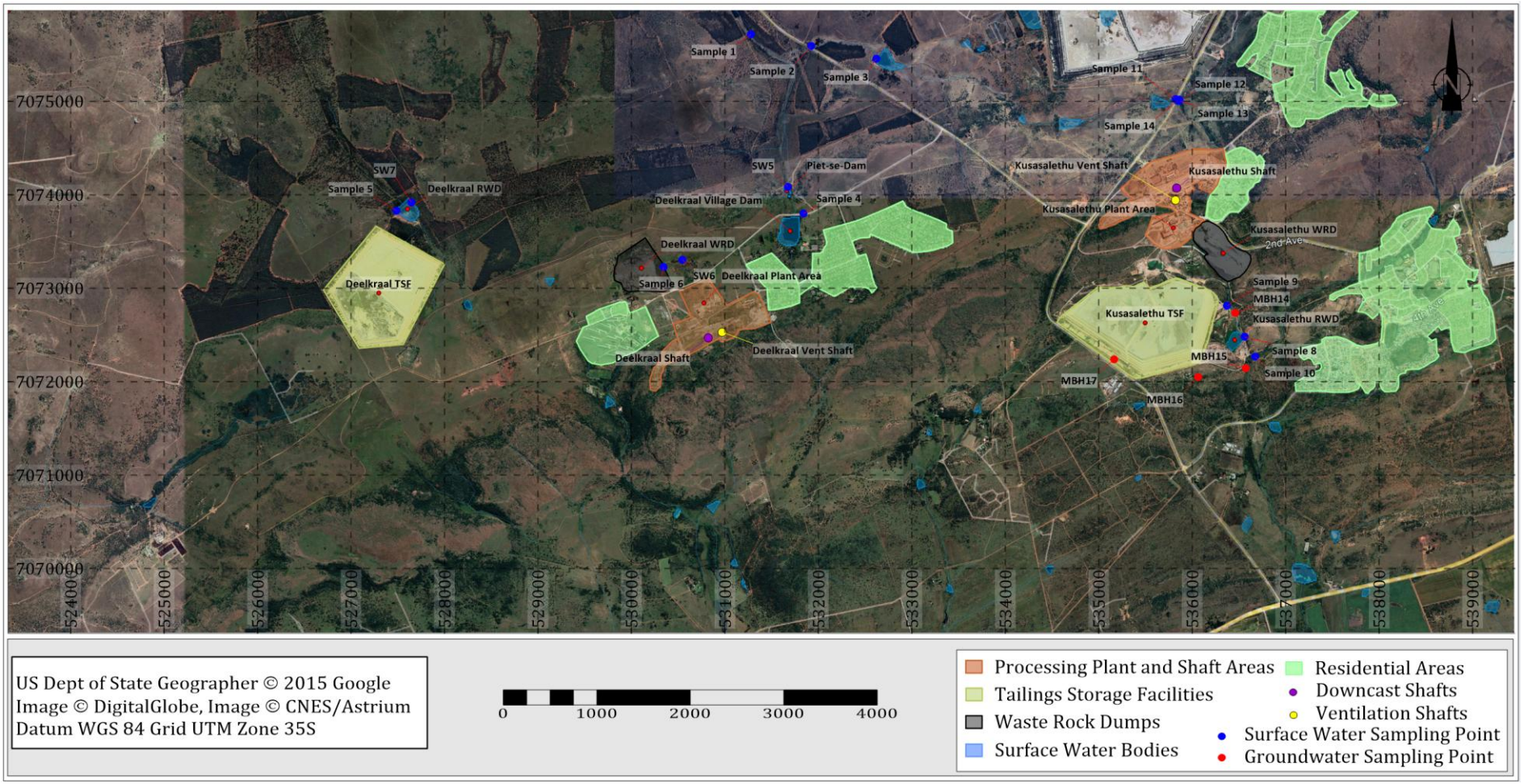


Figure 3.53 **Map showing the location of surface water and groundwater monitoring points available to determine the potential influence of the aquatic pathway on the total annual effective dose (see Table 3.8 and Table 3.30 for description).**



Figure 3.54 Sediment samples from the Welverdiend stream measuring below and above 50 mg.kg^{-1} uranium.

Table 3.34 Radionuclide activity concentrations in surface water samples collected from the Golf Course sampling point.

Sampling Date	14/01/2011	29/06/2011	24/01/2012	04/07/2012	18/12/2012	02/10/2013	15/01/2014
Necsa Report No.	RA-11101	RA-11694	RA-12579	RA-13187	RA-13905	RA-14805	RA-15360
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	8.28	14	76.3	179	8.2	338	291
U-234	11.7	13.4	77.1	178	17.2	299	261
Th-230	41.6	25	110	36.8	21	76.5	33
Ra-226	2.2	3.38	44.4	27	3.52	17.2	26.1
Pb-210	1.6			0.18	4.2	7.9	
Po-210	1.6	4.06	1.3	0.18	4.2	7.9	3.92
U-235	0.381	0.645	3.51	8.08	0.378	15.5	13.4
Th-227	6.34	3.8	4.36	11.4	10.8	6.2	2.8
Ra-223	0.65	-1	2.08	0.27	0.23	3.62	1.37
Th-232	3.1	0.47	8.58	7.51	2.6	4.06	3.85
Th-228	3.1	14.3	12.5	9.59	5.86	5.38	17
Ra-224	<MDA	<MDA	2.1	1.9	1.3	< MDA	<MDA
Gross α	51	-21	280	280	100	539	644
Gross β	51	-46	2300	140	240	806	596

Sampling Date	01/07/2014	15/01/2015	29/09/2015	08/06/2017	19/01/2018	24/08/2018	15/07/2019
Necsa Report No.	RA-16119	RS2015-0028	RS2015-3104	RS2017-2544	RS2018-0213	RS2018-4055	RS2019-3314
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	514	666	528	281	10.6	260	128
U-234	475	652	514	286	28	437	138
Th-230	33	37.1	19.6	9.8	16.8	17.1	15
Ra-226	79.4	31.2	46.4	54.2	11.9	6.57	14.2
Pb-210	0		3.9		14.5		5.24
Po-210	13.7	22.4	3.9	2	14.5	3.83	5.24
U-235	23.7	30.5	24.3	12.9	0.488	12	5.89
Th-227	67.2	19.8	5.6	8.11	11.3	10	6.62
Ra-223	-7.3	1.2	0.64	10.4	1.3	< MDA (1.4)	0.31
Th-232	2.5	6.35	3.58	1.5	8.31	1.7	14.6
Th-228	9.9	6.2	6.56	7.5	4.09	4	9.71
Ra-224	-2.1	15.9	< 3.2	5.8	< MDA (3.9)	1.5	1.2
Gross α	691	658	904	336	< MDA (610)	110	183
Gross β	1060	737	1010	691	110	669	539

Sampling Date	13/08/2019	06/02/2020	11/08/2020	17/03/2021	17/11/2021	08/02/2022
Necsa Report No.	RS2019-3813	RS2020-0473	RS2020-2567	RS2021-0987	RS2021-3553	RS2022-0352
Radionuclide	Activity Concentration ($mBq.L^{-1}$)					
U-238	589	520	123	33.6	243	762
U-234	568	489	111	37.1	248	736
Th-230	35	18.6	17.7	11	< MDA	<21
Ra-226	267	8.21	2.33	13.4		134
Pb-210		8.55				
Po-210	2.8	8.55	0.947	8.02	1.36	4.29
U-235	27.1	23.9	5.66	1.55	11.2	35.1
Th-227	18	3.3	9.78	< MDA	12.4	14.4
Ra-223	< MDA (1.4)	3.17	4.61	0.12	< MDA	< MDA
Th-232	18.4	2.22	5.82	1.22	48.8	6.92
Th-228	6.6	1.6	9.21	5.66	29.6	9.83
Ra-224	2.41	2.5	12.8	1.4	9.66	< MDA
Gross α	2980	57	89	81.7	548	1360
Gross β	2730	140	1040	237	655	1540

Table 3.35 Radionuclide activity concentrations in surface water samples collected from the Deelkraal Village Dam sampling point.

Sampling Date	14/01/2011	29/06/2011	24/01/2012	04/07/2012	18/12/2012	02/10/2013	15/01/2014
Necsa Report No.	RA-11101	RA-11694	RA-12579	RA-13187	RA-13905	RA-14805	RA-15360
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	58.8	187	140	427	812	1300	1580
U-234	66.7	174	108	433	782	1290	1430
Th-230	418	7.34	43.4	116	56.7	25.4	111
Ra-226	4.9	3.57	14.2	11.1	11.2	17.8	20.4
Pb-210				25.7	1.75	5.7	
Po-210	4.8	1.3	1.3	25.7	1.75	5.7	1.5
U-235	2.71	8.61	6.44	19.7	39.1	59.8	72.7
Th-227	9	4	2	7	6.9	2.85	6.7
Ra-223	1.9	1.1	0.68	1.9	-0.29	2.17	0.99
Th-232	24	0.4	10.9	3.9	5.2	2.3	8.1
Th-228	13.9	5.58	28.1	5.87	7.46	6.39	15.9
Ra-224	<MDA	< M D A	0.98	6.4	<MDA	< MDA	<MDA
Gross α	96	160	36	554	1150	2660	2570
Gross β	-47	68	1900	420	818	1260	1830

Sampling Date	01/07/2014	15/01/2015	29/09/2015	08/06/2017	19/01/2018	24/08/2018	15/07/2019
Necsa Report No.	RA-16119	RS2015-0028	RS2015-3104	RS2017-2544	RS2018-0213	RS2018-4055	RS2019-3314
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	603	664	371	1050	1500	740	529
U-234	547	628	360	1020	1430	720	531
Th-230	34.6	17	38.5	10	24.3	6.4	22.8
Ra-226	11.1	14.1	8.36	27.8	36.2	11.4	13.7
Pb-210			5.48		21.5		7.53
Po-210	3.67	1.6	5.48	8.72	7.07	6.77	7.53
U-235	27.8	30.6	17.1	48.1	69	34.1	24.4
Th-227	5.5	4.2	6.2	7	26.7	7.4	5.66
Ra-223	5.1	2	-0.28	36.9	0.043	< MDA (1.7)	< MDA (0.98)
Th-232	4.89	-0.76	5.78	4.1	2.9	1.1	3.23
Th-228	9.71	2.25	7.98	10.2	9.46	< MDA (10)	5.09
Ra-224	1.6	15.4	< 3.3	29.7	1.3	1.8	0.94
Gross α	1020	1000	607	1450	1890	1000	874
Gross β	726	645	616	2120	1270	1040	1650

Sampling Date	13/08/2019	06/02/2020	11/08/2020	17/03/2021	17/11/2021	08/02/2022
Necsa Report No.	RS2019-3813	RS2020-0473	RS2020-2567	RS2021-0987	RS2021-3553	RS2022-0352
Radionuclide	Activity Concentration ($mBq.L^{-1}$)					
U-238	374	1710	790	522	1030	271
U-234	342	1520	772	489	978	287
Th-230	35	12.3	43.6	10	47.2	< MDA
Ra-226	10	27.8	22.5	6.68	27.5	3.62
Pb-210		9.06				
Po-210	7.16	9.06	3.27	9.12	< MDA	2.64
U-235	17.2	78.9	36.4	24	47.2	12.5
Th-227	21.3	3.3	6	7.8	21.8	12.1
Ra-223	4.71	3.84	3.7	1.6	15.4	3.75
Th-232	30.4	1.96	3.8	2.12	9.95	3.76
Th-228	10.4	5.24	5.2	16.4	9.78	7.48
Ra-224	0.81	1	48.4	1	8.19	10.2
Gross α	1010	2710	1290	850	1850	324
Gross β	240	2010	2620	815	1180	702

Table 3.36 Radionuclide activity concentrations in surface water samples collected from the Wedela Stream sampling point.

Sampling Date	14/01/2011	29/06/2011	24/01/2012	04/07/2012	18/12/2012	02/10/2013	15/01/2014
Necsa Report No.	RA-11101	RA-11694	RA-12579	RA-13187	RA-13905	RA-14805	RA-15360
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	7.38	4.1	6.89	9.47	27.3	17.3	13.5
U-234	20	4.37	13.5	17.8	57	22.5	66.9
Th-230	238	52.7	9.2	47.1	33.2	18	55.6
Ra-226	0.29	2.87	2.84	5.61	1.97	8.35	3.04
Pb-210				3.98	17.7	4.46	
Po-210	3.56	0.78	2.59	3.98	17.7	4.46	5.29
U-235	0.34	0.189	0.317	0.436	1.26	0.795	0.622
Th-227	8.8	-1.3	1.5	9.81	13.3	3	5.8
Ra-223	2.39	-0.6	1.5	2.3	0.97	1.92	-0.24
Th-232	8.67	1.56	1.58	14.9	7.37	0.58	11.4
Th-228	20.2	8.23	3.54	21.5	20.8	5.19	5.35
Ra-224	5.25	<MDA	0.91	20.5	1.4	1.4	1.3
Gross α	9	-56	2.2	74	22	12	110
Gross β	-150	-120	1330	21	8	180	352

Sampling Date	01/07/2014	15/01/2015	29/09/2015	08/06/2017	19/01/2018	24/08/2018	15/07/2019
Necsa Report No.	RA-16119	RS2015-0028	RS2015-3104	RS2017-2544	RS2018-0213	RS2018-4055	RS2019-3314
Radionuclide	Activity Concentration ($mBq.L^{-1}$)						
U-238	21.6	7.41	4	7.56	18.3	64.6	119
U-234	30	8.92	21.2	11.2	28.8	251	122
Th-230	38.4	13	36.4	7.7	26	5.4	20.8
Ra-226	21.9	3.6	1.96	9.15	8.24	7.29	9.44
Pb-210			14.3		262		6.54
Po-210	3.95	13	14.3	9.41	< MDA (1.3)	7.45	6.54
U-235	0.994	0.341	0.184	0.348	0.844	2.98	5.46
Th-227	4.6	7.3	4.5	11.2	10.9	9.08	6.2
Ra-223	-4.1	3.5	0.66	8.7	< MDA (1)	0.76	0.068
Th-232	2.92	4.13	6.15	1.3	4.1	1.8	8.31
Th-228	2.9	14.3	17.3	12.6	1.3	2.4	3.5
Ra-224	0.68	0.15	<3.6	12.2	< MDA (3.1)	< MDA (5.8)	< MDA (2.5)
Gross α	180	-76	71	< MDA (120)	< MDA (180)	61	309
Gross β	200	210	3.2	70	110	238	531

Sampling Date	13/08/2019	06/02/2020	11/08/2020	17/03/2021	17/11/2021	08/02/2022
Necsa Report No.	RS2019-3813	RS2020-0473	RS2020-2567	RS2021-0987	RS2021-3553	RS2022-0352
Radionuclide	Activity Concentration ($mBq.L^{-1}$)					
U-238	32.2	61.9	46.5	7.46	34	6.43
U-234	37.9	58	50.6	16.2	81.9	24.1
Th-230	55.1	14	58.7	18	68.1	< MDA
Ra-226	12.8	16.2	6.37	2.16	9.78	9.7
Pb-210		14.4				
Po-210	8.15	14.4	1.47	2.61	3.04	1.8
U-235	1.53	2.85	2.14	0.343	1.56	0.296
Th-227	21.1	4.8	< MDA (9.9)	11	18	11.7
Ra-223	1.84	< MDA (1.5)	4.42	0.29	< MDA	< MDA
Th-232	20.3	1.6	11.9	3.8	18.6	4.27
Th-228	13.7	2.81	8.88	12.8	16	7.65
Ra-224	1.79	2.44	21.2	0.76	< MDA	< MDA
Gross α	82.7	94.7	17	4.1	177	< MDA
Gross β	< MDA (240)	< MDA (290)	1580	23	243	< MDA

Table 3.37 Summary of full spectrum analysis of three sediment samples from the Welverdiend stream (Necsa Report No. RA-12822 dated 6 June 2012).

Sampling Date	11/04/2012	11/04/2012	11/04/2012
Sampling Point	MMS 11A	MMS 7B	MMS 1C
Radionuclide	Activity Concentration ($Bq.kg^{-1}$)		
U-238	632	421	97.4
U-234	637	425	98.2
Th-230			
Ra-226	54.9	50.6	57.9
Pb-210	69.1	< MDA	55
Po-210			
U-235	29.1	19.4	4.49
Th-227			
Ra-223			
Th-232	21.9	37.4	34.2
Ra-228	32.3	57.2	42.9
Th-228	26.6	43.7	38.3
K-40	169	215	323
Gross α	2120	1720	1190
Gross β	1190	953	646

3.8.3.3 Groundwater

Groundwater is not monitored as extensively at the Kusasalethu Operations as surface water. Only one full-spectrum radioanalysis result is available for 4 groundwater sampling points. The locations of the four monitoring boreholes are indicated in Figure 3.53, and the geographic coordinates for each are listed in Table 3.8. Table 3.38 summarises the results from samples collected in 2014.

Table 3.38 Radionuclide activity concentrations in groundwater samples collected in November 2014 (Necsa Report No. RS2014-0632-01 dated 25 March 2015).

Sampling Date	14/11/2014	14/11/2014	14/11/2014	14/11/2014
Sampling Point	MBH 14	MBH 15	MBH 16	MBH 17
Radionuclide	Activity Concentration ($mBq.L^{-1}$)			
U-238	56.1	29.1	55.5	24.7
U-234	197	71.1	100	62.7
Th-230	13	89.3	19.6	16
Ra-226	132	93.1	57.6	40.8
Po-210	74.2	16	37	67.9
U-235	2.58	1.34	2.55	1.14
Th-227	13.8	16.3	6.3	20.9
Ra-223	-1.9	-3.9	-2.4	-2.6
Th-232	5.24	17.5	6.82	12.3
Th-228	17.2	29.1	6.73	11.4
Ra-224	4.47	6.4	0.92	5.06
Gross α	140	190	422	190
Gross β	560	130	709	150

3.8.3.4 Dust Fallout

Recent dust filter monitoring results for 2023 have been provided, but historical monitoring data is not available. Radioanalysis results for only U-238, U-234 and U-235 are available for 6 sampling points. The locations of the six sampling points are presented in Table 3.12 and Figure 3.30. Table 3.39 summarises the results.

Table 3.39 Radionuclide activity concentrations in dust filter samples collected in November 2023 (Necsa Report No. RS2023-3298-01 dated 05 February 2024).

Sampling Date	16/11/2023	16/11/2023	16/11/2023	16/11/2023	16/11/2023	16/11/2023
Sampling Point	DK1	DK6	ER3	ER4	ER5	ER7
Radionuclide	Activity Concentration (Bq.kg^{-1})					
U-238	88.3	352	442	263	191	305
U-234	89	355	446	265	193	307
U-235	4.06	16.2	20.4	12.1	8.81	14

3.8.3.5 Fish

Botha (2005) reported full-spectrum radioanalysis results of fish caught in the Deelkraal Dam in 200 and 2003. Table 3.40 summarises the results.

Table 3.40 Full-spectrum radioanalysis results for fish caught in the Deelkraal Dam in 2000 and 2003 (Botha, 2005).

Sampling Date	2000	2003
Necsa Report No.	RA-03306	-
Sampling Point	Deelkraal Dam	
Radionuclide	Fish Sample Activity (Bq.kg^{-1})	
U-238	34.1	9.52
Ra-226	<25	-0.04
Pb-210	<8.4	0.61
Po-210	<6.0	0.61
U-235	1.57	0.44
Th-232	<15	0
Ra-228	<36	0.428
Th-228	<29	0.23
Gross α	3.71	0.03
Gross β	1.27	0.1

4 Definition of Public Exposure Conditions

4.1 Introduction

The primary goal of the radiological public safety assessment is to evaluate the potential impact of the Project on public health during its operational phase. Where necessary and justified, consideration is also given to the potential impact during the post-closure period. Public exposure to ionising radiation may vary depending on operational conditions and the timeframe considered (present or future).

Consistent with the assessment framework presented in Figure 1.5, the radiological public impact is evaluated by developing site-specific public exposure conditions. As used here, an exposure condition is defined as follows:

> *An exposure condition is a sequence of features, events, and processes (FEPs) and is one of a set devised to illustrate normal or potential situations of radiation exposure to receptors.*

This section aims to establish and justify site-specific public exposure conditions for the Project using current operational knowledge (see Section 3.4 and Section 3.5) and the defined context (see Section 2). A Source-Pathway-Receptor (SPR) analysis approach was selected as it is systematic, traceable, and transparent, allowing for the identification and evaluation of all potential exposure scenarios, both current and future (see Figure 1.5).

The section is structured as follows. Section 4.2 defines a few key concepts used in the SPR analysis approach. At the same time, the elements of the SPR linkages relevant to the Project are evaluated and discussed in Section 4.3 to Section 4.5. Section 4.7 introduces how conceptual models are represented in the definition of exposure conditions. The outcome of the SPR analysis is then used to define and justify the public exposure conditions in Section 4.8.

4.2 Key Concepts Used in the SPR Analysis Approach

The SPR analysis approach is inherently systematic, traceable and transparent, and comprises three interrelated steps to evaluate radiation exposure conditions defined for a mining and mineral processing operation.

- **Source Identification**: Identify and characterise all relevant sources of radiation exposure (current, future, and historical, if applicable). Sources are characterised by their unique composition (i.e., specific radioactive substances present or emitted) and by characteristics that determine how contaminants may be distributed in the environment.
- **Pathway Evaluation:** Evaluate all relevant pathways and routes of exposure associated with the identified sources. *Pathways* describe how radionuclides move through the environment to points of human interaction, while *exposure routes* refer to how radiation enters the human body (e.g., ingestion, inhalation, or external exposure).
- **Receptor Characterisation**: Define and evaluate potential *receptors*, i.e., humans who may be exposed to radiation (i.e., in terms of a radiation dose) through the identified sources and pathways of the mining and mineral processing operation.

4.3 Source Identification

4.3.1 General

Sources of radiation exposure to members of the public associated with mining and mineral processing facilities are often inadvertently induced. Although the key elements responsible for radiation exposure are naturally occurring radionuclides, human-induced conditions and activities may increase their concentrations in the accessible environment. Alternatively, the potential for human exposure to naturally occurring radionuclides in products, by-products, residues, and other wastes may increase if these radionuclides are moved from inaccessible locations to locations where humans can be exposed to radiation.

To pose a radiological risk to the public and the environment, radionuclides must first be released from sources of radiation exposure. As used here, *sources* refer to any entity that contains radioactivity *and* has the potential to release radioactivity into the environment. Release mechanisms can be generalised into the following natural and human-induced conditions:

- The release of radionuclides through natural conditions:
  - Solid release (e.g., windblown dust);
  - Water-mediated release (e.g., leaching through the tailings storage facility); and
  - Gas-mediated release (e.g., radon gas exhalation).
- Direct gamma radiation; and
- Controlled or uncontrolled releases of radionuclides as solids or liquids into the environment.

Controlled releases are human-induced under normal operating conditions. In contrast, uncontrolled releases are associated with accidents and incidents outside normal operating conditions (e.g., excessive water erosion, pipeline bursts, releases from storage dams exceeding capacity, or dam wall failures).

4.3.2 Primary and Secondary Sources of Radiation Exposure

A distinction can be made between primary and secondary sources of radiation exposure. The *primary sources* are associated with physical features or entities at a mining and mineral processing operation. They may pose a potential for releasing naturally occurring radionuclides into the environment. Examples of primary sources generally associated with mining and mineral processing operations include:

- Tailings Storage Facilities (TSFs), Waste Rock Dumps (WRDs) or any other stockpile facility used to store waste or other residue material on the surface, from which naturally occurring radionuclides may be dispersed in solid (dust), liquid (seepage), or gaseous (radon gas) form.
- Mineral processing activities, where radioactive gases and dust may be released from the comminution (e.g., crushing, milling, and screening) and beneficiation of ore containing radionuclides.
- Water management facilities (e.g. return water dams, process control dams, and evaporation ponds), used to manage excess water generated through mining, mineral processing, and residue disposal activities, and where water may be released to the environment.
- Materials handling activities (e.g., loading and hauling or the transfer of material containing naturally occurring radionuclides from one point to another), during which radioactive dust may be released to the environment.
- Mine ventilation shafts are used to increase airflow in underground workings, where gases and dust generated underground may be released with the outflowing air.

Radioactivity released from primary sources into the environment may accumulate in environmental compartments (e.g., groundwater, surface water bodies, the upper soil layer, sediments), potentially creating *secondary sources* of radiation exposure. The following serve as examples of secondary radiation sources:

- Continuous deposition and accumulation of naturally occurring radionuclides associated with airborne dust or contaminated irrigation water on the upper soil layer, resulting in the development of a secondary source at the soil surface.
- Continuous deposition of naturally occurring radionuclides associated with airborne dust in a surface water body results in the development of a secondary source in the sediments and surface water body.
- Uncontrolled release of contaminated mine residue (e.g., tailings material) through surface water erosion of existing stockpile facilities.
- Uncontrolled release (e.g., spillage) of contaminated mine residue (e.g., tailings material) or water on surface soils from pipelines or storage dams, resulting in the development of a secondary source at the soil surface.
- Uncontrolled release (e.g., spillage) of contaminated mine residue (e.g., tailings material) or water in a surface water body from pipelines or storage dams (as appropriate), resulting in the development of a secondary source in the sediments and surface water body.

Members of the public may be exposed to radiation from both primary and secondary sources at a mining and mineral processing operation, with expected differences in exposure modes and duration. The purpose of Section 4.3.3 and Section 4.3.4 is to provide a brief description of the potential primary and secondary sources of radiation exposure associated with the Project. Note that the significance of these sources may vary and may change over time during the LoM.

4.3.3 Primary Sources Associated with the Project

4.3.3.1 General

Facilities, activities and associated surface infrastructure of the Project that are known to contain or emit ionising radiation were presented in detail in Section 3. Table 4.1 summarises the facilities and activities that may contribute to radiation exposure.

Some primary sources of radiation exposure are expected to change during the life cycle of the Project. The *Assessment Context* defined in Section 2 distinguished between an operational and a post-operational period. The nature of mining and mineral processing operations means that some sources present during the operational period will no longer be active after closure. The operational phase, therefore, represents the ‘worst case’ because it has the highest number of identified sources and serves as the basis for the development of public exposure conditions for the radiological public safety and impact assessment of the Project.

Other surface infrastructure, such as roads, offices, and laboratories, does not release naturally occurring radionuclides into the environment and is not considered a source of radiation exposure to the public *per se*.

Table 4.1 Summary of surface infrastructure and features of importance to the Project radiological public safety and impact assessment.

Area	Feature	Description	Category
Former Elandsrand Mine	Tailings Storage Facility	One operational tailings storage facility consisting of two compartments. Plans are underway to remine the existing TSF as part of the Project.	TSFs
	Elandsrand Return Water Dam (unlined)	No. 1 and No. 2 dams serve as return-water dams for the TSF complex.	Surface Dams
	Unlined trenches	Trenches used for the flow of water draining from the TSF	Trenches
	Waste Rock Dump	Operational. Reclaimed as aggregate, under NNR-approved safety assessment.	WRDs
	Metallurgical Mineral Processing Plant	Operational, with a total capacity of approximately 220,000 tonnes/month. Processing occurs in a closed circuit. Currently processing approximately 60,000 tonnes/month	MET Plants
	Upcast and Downcast Shafts	Two vertical shafts, one for workers and material and one for rock and ventilation.	Shafts
Former Deelkraal Mine	Tailings Storage Facility	The Deelkraal TSF is non-operational and is currently maintained by a contractor to ensure its physical integrity. Plans are underway to remine the existing TSF as part of the Project.	TSFs
	Waste Rock Dump	Non-operational. Reclaimed, but the footprint still has to be rehabilitated.	WRDs
	Metallurgical Mineral Processing Plant	Demolished and rehabilitation is ongoing. 70% completed, with concrete base remaining.	MET Plants
	Deelkraal Dam and Piet se Dam	Both are non-operational; currently, no wastewater is recovered from the former Deelkraal mine.	Surface Dams
	Upcast and Downcast Shafts	3 shafts: 2 non-operational, one used for upcast of the underground ventilation.	Shafts
Proposed New Infrastructure	Tailings Storage Facility	Remining of the existing Deelkraal 1 TSF and the Kusasalethu TSF, and construction of the Deelkraal II TSF.	TSFs
	Metallurgical Mineral Processing Plant	Upgrades to the existing Kusasalethu plant, including new/upgrade of gold and new uranium sections	MET Plants
	New Return Water Dam	An underdrainage system is provided beneath the RWD basin.	Surface Dams
General	Various (undefined)	Surface water release points.	Releases
	Various (undefined)	Historic incidents and spillages that may be considered secondary sources	Incidents
	Pipelines	Pipelines used for the transfer of water and tailings materials between different components of the operation	Pipelines

4.3.3.2 Tailings Storage Facilities

A TSF can measure a few kilometres in circumference and can be tens of metres high. The surfaces of operational or dormant TSFs are generally susceptible to wind erosion. Rehabilitation efforts on dormant TSFs or on disused sections of operational TSFs can reduce windblown dust. TSFs are also equipped with underdrains to prevent seepage, as well as a diversionary drainage system around the TSF perimeter to store and control stormwater and sediment washed off the TSF walls. Both seepage and run-off are drained back into the return water or process water dams for re-use.

A TSF generally serves as a source of radiation exposure through solid-, gas- and water-mediated release of contaminants in the following manner:

- Windblown dust emitted from the TSFs may contain long-lived alpha-emitting isotopes, which are dispersed into the atmosphere (solid-mediated release of contaminants, increasing airborne activity concentrations). This radioactive dust is generally referred to as long-lived alpha-particle-emitting dust (LLα).
- The Ra-226 content of the tailings material may result in the emission of radon gas into the air (gas-mediated release of contaminants, increasing *airborne activity concentrations*).
- Infiltration and subsequent percolation of water through the TSFs may induce leaching of radionuclides to the underlying geosphere (water-mediated release of contaminants, increasing *groundwater activity concentrations*).
- Water erosion of the TSFs may induce the solid-mediated release of contaminants, increasing *surface soil activity concentrations*.

Although not a contaminant in the usual sense, the tailings material's inherent radiological properties may result in continuous gamma radiation emissions from these sources (*external gamma radiation*). As described in Section 3, two TSFs are earmarked for reprocessing: the Deelkraal 1 TSF and the Kusasalethu TSF. The reprocessed tailings material will be deposited on the proposed new Deelkraal II TSF.

4.3.3.3 Water Management Infrastructure

According to the System Description (see Section 3), several water management facilities are associated with the historical TSFs (e.g., return-water dams, paddocks, and trenches).

The nature of these water management facilities is such that the only contribution to radionuclide release is through water infiltration and subsequent leaching of radionuclides into the underlying geosphere (water-mediated release of contaminants, increasing *groundwater activity concentrations*). However, the return water dam is fitted with a double high-density polyethene (HDPE) liner to prevent seepage and should be in the post-operational phase, with no water applications. While these dams are within the Project's mining authorisation, public access to these facilities cannot be excluded.

4.3.3.4 Pipelines

It follows from the *System Description* (see Section 3.4) that the Project uses extensive pipeline surface infrastructure to transfer water and tailings over distances. Under normal operating conditions, these pipelines do not serve as a significant source of radiation exposure. It is only under accident and incident conditions (e.g., pipeline bursts) that these pipelines may serve as a potential secondary source of radiation exposure (see Section 4.3.4).

4.3.4 Secondary Sources Associated with the Project

4.3.4.1 General

Generally, secondary sources of radiation exposure, as introduced and defined in Section 4.3.2, may be induced by natural processes and events, as well as by normal operating conditions of a mining and mineral processing operation.

4.3.4.2 Natural Processes and Events

Secondary sources induced by natural processes and events refer to the release of naturally occurring radionuclides from the primary sources (see Section 4.3.3), their distribution through the environmental system (see Section 4.4), and the subsequent build-up of activity in the associated environmental compartments with time (e.g. surface soils, surface water bodies and sediments). The development of secondary sources through these natural processes and events is thus a gradual but continuous process that can be regarded as an extension of the environmental pathways (see Section 4.4) and, as a result, is addressed as such in the assessment.

The second category of natural processes and events that contribute to secondary sources is induced by surface-water erosion. During high-rainfall events and over time, surface-water erosion of the tailings storage facility transfers material, leading to solid-mediated contaminant release (runoff). Due to the nature of these events, the tailings will be deposited in lower-lying areas often associated with surface water streams and wetlands, resulting in secondary sources in these areas.

4.3.4.3 Normal Operating Conditions

While natural processes and events discussed in Section 4.3.4.2 can be classified as normal operating conditions, this category of secondary sources specifically pertains to releases permitted under the approved operational conditions of the Project. Two illustrative examples are as follows:

- **Authorised Water Discharges**: The first example involves the Annual Authorised Discharge Quantities (AADQ) of water released into the environment during high rainfall events or when water is decanted from underground workings as pumping ceases. These water releases may serve as secondary sources of radiation exposure for the public.
- **Material Spillages or Windblown Dust**: The second example refers to gradual, continuous spillages or windblown dust from trucks transporting products or residue materials between locations during the mining operation. When these materials are deposited along public roads, they create secondary sources of radiation exposure in surrounding areas.

Both examples would require pre-authorisation from the relevant authorities before they can be incorporated into the environmental management program. For instance, the conditions governing water releases to the environment are typically approved as part of the mine's water-use license. From a public radiation protection perspective, any such conditions at the Project must be identified and incorporated into the radiological public safety assessment as potential sources of radiation exposure.

4.3.4.4 Secondary Sources Due to Events Outside Normal Operating Conditions

This category of secondary sources arises from discrete disruptive events that occur outside the normal operating conditions of a mining and mineral processing operation, leading to water- or solid-mediated releases of naturally occurring radionuclides into the environment. These events, classified as accidents or incidents, typically occur over short time scales compared to the mine's operational lifespan. Several components within the Project are susceptible to such disruptive events:

- **Pipelines:** Used to transport water or tailings within the mining operation. When implemented, operated, and maintained as designed, pipelines do not act as a source of radiation exposure. A pipeline burst could release contaminants via solid-mediated mechanisms. If the spill occurs on land, it could elevate surface soil activity concentrations. If it occurs near or at a surface-water crossing, it may increase surface-water activity concentrations, potentially creating secondary sources of radiation exposure.

- **Water Management Facilities:** These facilities are designed and engineered to contain specific volumes of water in accordance with regulations such as Government Notice No. 704 (1999), which ensure the protection of water resources during normal operations. Failure in the functionality or design of these facilities could result in water releases into the environment. Such releases may increase activity concentrations in surface soil or surface water, becoming secondary sources of radiation exposure.
- **Tailings Storage Facilities:** These facilities are designed using advanced engineering and geotechnical principles to accommodate the tailings material generated during the mine's operational life. Features like underdrains, toe paddocks, and dams manage seepage and runoff under normal conditions. Excessive water erosion could cause tailings material to be discharged into the environment. Catastrophic failures (e.g., dam instability or collapse, such as the Merriespruit disaster) could lead to significant releases of tailings into surrounding areas, causing widespread contamination of soil and water and creating substantial secondary sources of radiation exposure.

The cases mentioned above illustrate disruptive events beyond the normal operations of a mining and mineral processing site that could lead to secondary radiation exposure. Additional examples may vary depending on site-specific and operational conditions. It is crucial to recognise that the likelihood of such events occurring is uncertain, as is their magnitude in terms of scale and duration. This uncertainty also extends to the significance of secondary sources resulting from these events, since potential public radiation exposure depends on the event's size and nature. For instance, the radiological impact of a pipeline burst lasting an entire year would differ significantly from that of one lasting a single day. Similarly, the consequences of tailings material spillage in an open veld would differ from those of spillage into a surface water body. The risks posed by a catastrophic event, such as a Merriespruit-type disaster, are distinct from those associated with localised water-induced erosion of tailings storage facilities.

While it is important to acknowledge that these discrete, isolated events may occur, the parameter values required to assess the public impact of secondary sources resulting from such events would be hypothetical and uncertain. Due to the numerous uncertainties surrounding the occurrence and nature of these events, they cannot be included in the operational radiological public safety assessment process, as outlined in RG-002 NNR (2013). However, this does not imply that the potential radiological consequences of disruptive events are overlooked within the broader radiation protection framework established at the Project.

The approach to managing disruptive events is outlined in detail in the NNR-approved Radiation Management Plan, which includes various procedures (e.g., physical security, radiation function, emergency preparedness, and occurrence reporting procedures). Regarding emergency preparedness, the emergency response plan is activated immediately upon identification of an accident or incident, with a focus on maintaining radiation doses as low as reasonably achievable (ALARA).

In line with the radiation function procedure, specific actions must be taken on the day the incident or accident is identified, with additional actions required as soon as possible thereafter. These actions include, among others:

- Assessing the extent of physical damage to property, people and the environment, as well as the extent of the contamination in and around where the event occurred, using appropriate radiation survey equipment and taking water samples upstream and downstream of the incident, as appropriate;
- Inform the NNR about the event, including the current situation and its development, measures taken to protect workers and members of the public, and the exposures that have occurred and those expected to be incurred;

- Initiate the clean-up process, with due consideration of the extent of the contamination, the potential radiological impact on workers and members of the public, and appropriate mitigation measures that can be implemented in the interim to contain the risks; and
- Capture all relevant information in an Occurrence Report to be submitted to the NNR according to the Procedure for the Reporting of Occurrences, taking cognisance of how, when and where the event happened, corrective actions and clean-up operations, and the radiological impact on workers and members of the public.

While the steps listed above are not necessarily comprehensive for the emergency preparedness procedure, they certainly illustrate due process to ensure that members of the public are protected from disruptive events outside the normal operating conditions of a mining and mineral processing operation that might lead to secondary radiation exposure. For this reason, potential secondary sources of radiation exposure arising from events outside normal operating conditions will not be explicitly considered in the Project. However, recommendations will be made, as appropriate, to ensure they are adequately covered in the Radiation Management Plan of the Project.

Although the steps outlined above may not be exhaustive for the emergency preparedness procedure, they demonstrate the necessary process to protect the public from disruptive events outside the normal operating conditions of a mining and mineral processing operation that could lead to secondary sources of radiation exposure. As a result, potential secondary sources of radiation exposure caused by events outside normal operations will not be explicitly addressed in the Project. However, appropriate recommendations will be made to ensure these scenarios are adequately covered in the mine's Radiation Management Plan.

4.3.5 Summary

Table 4.2 summarises the radiological hazards associated with the primary and secondary sources discussed in Section 4.3. Radiological hazards specific to the operational phase of the Project are considered.

Table 4.2 Summary of the potential radiological hazards associated with the operational phase of the Project.

Sources	Radiological Hazards
Mineral Processing Plant (materials handling)	Airborne LLα
Existing and proposed Kusasalethu and Deelkraal TSFs	Airborne LLα Radon Waterborne radionuclides Gamma radiation
Kusasalethu WRD	Airborne LLα (materials handling, crushing & screening) Waterborne radionuclides Gamma radiation
Kusasalethu and Deelkraal ventilation shafts	Airborne LLα Radon
Return Water Dams Process Water Dams Deelkraal (Village) Dam	Waterborne radionuclides (limited to direct exposure to the water by members of the public using the dam for recreational purposes)

4.4 Pathways

4.4.1 General

The primary environmental pathways through which members of the public may be exposed to radiation at mining and mineral processing operations can be summarised as follows (IAEA, 2002):

- **Atmospheric Pathway**: This results in exposure through the inhalation of airborne radioactive gases (e.g., radon and its decay products) and particulates.
- **Atmospheric and Terrestrial Pathways:** These lead to exposure from the ingestion of contaminated soil and foodstuffs, as well as external radiation from terrestrial sources.
- **Aquatic Pathways:** These involve exposure through ingestion of contaminated water; food produced with contaminated irrigation water; fish and other aquatic organisms; and food derived from animals that consume contaminated water. External radiation from water sources can also contribute.

Considering the potential radiation sources outlined in Section 4.3.3, the primary pathways of concern are atmospheric and groundwater, with the surface water pathway being of lesser significance. This section aims to demonstrate how contaminants may be transported through these pathways and how their interactions can distribute them to receptor locations.

4.4.2 Atmospheric Pathway

Particle size categories are typically used to assess particulate matter. Inhalable particulates are those with aerodynamic diameters less than 10 microns (PM_{10}), whilst the full particle size spectrum is normally referred to as Total Suspended Particulates (TSP). TSP is used in numerical dispersion modelling to represent dust deposition impacts, whereas modelled airborne PM10 concentrations are used to characterise health impacts from dust inhalation. The airborne particulates generated from the Project may include radionuclides. Deposition and inhalation of the particulates may also lead to radiation exposure.

The presence of Ra-226 in the tailings material further results in the exhalation of radon (Rn-222) gas into the atmosphere. Radon gas is distributed in the atmosphere, similar to particulates with small aerodynamic diameters, and can therefore reach off-site locations. Inhalation of radon gas can contribute to public radiation exposure. Generally, airborne particulates or radon gas concentrations are expected to be highest near the sources and to decrease with distance from the source, depending on meteorological conditions and the physical characteristics of the contaminants and the facilities from which they are released.

The sources identified in Section 4.3 relevant to the atmospheric pathway include the various tailings storage facilities and any other areas that may be contaminated with tailings or waste rock (e.g., through surface runoff to lower-lying areas). Using emission estimates from these sources, modelled airborne concentrations of PM_{10} and radon, as well as dust-fallout rates, were determined for the area of concern as part of an air quality impact assessment conducted for the Project (Airshed, 2026). These results confirm that airborne particulate or radon gas concentrations are highest near the sources and decrease with distance from them.

Figure 4.1 and Figure 4.2 present the current and future results from the air dispersion model as concentration isopleths, indicating the dispersion of airborne dust from all atmospheric pathway sources (TSFs and waste rock handling) combined. The isopleths represent annual-average PM_{10} concentrations and are expressed in $\mu g.m^{-3}$.

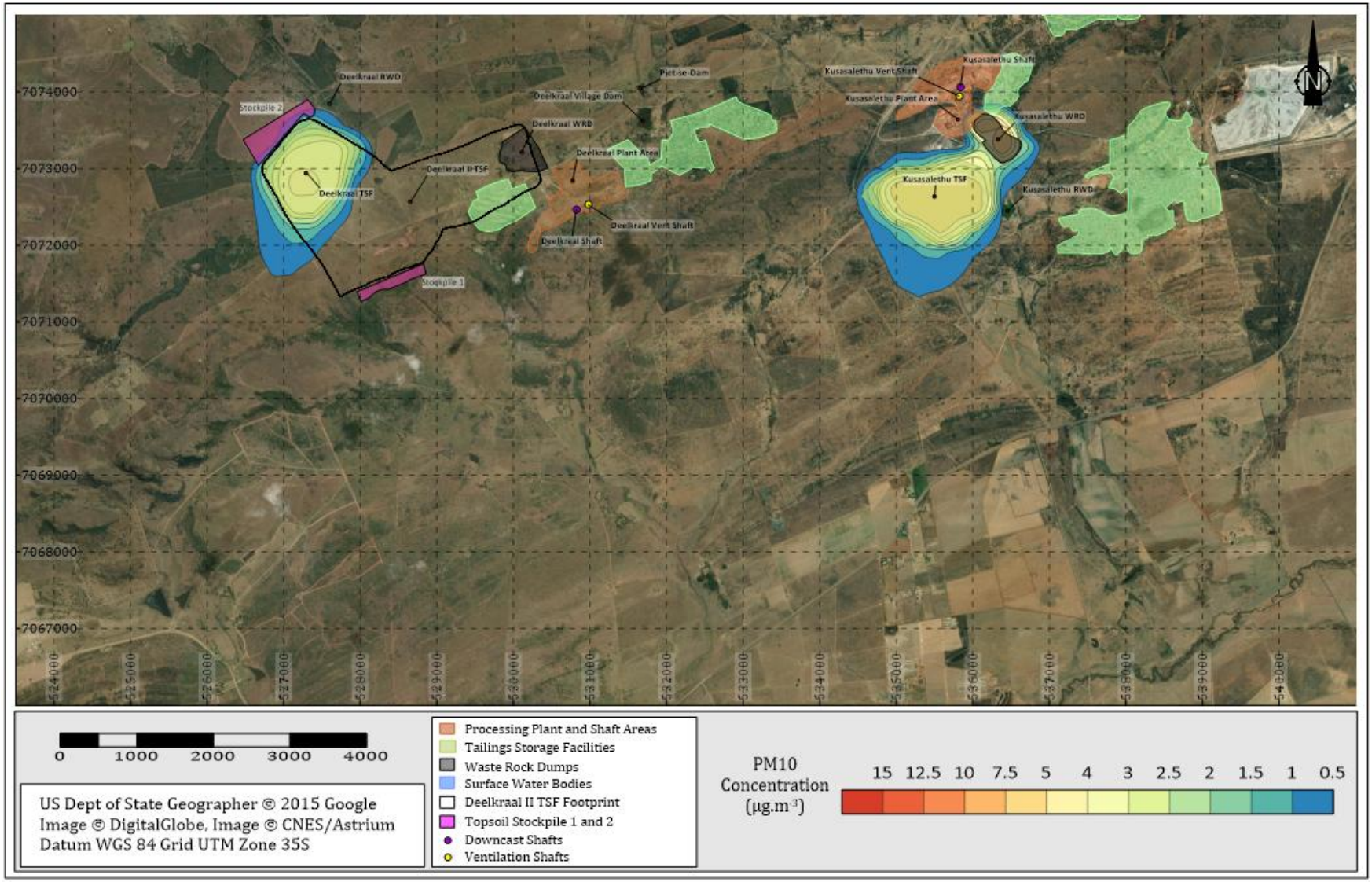


Figure 4.1 The simulated current annual average airborne PM_{10} concentrations (in units of $\mu g.m^{-3}$) attributed to the Kusasalethu Operations.

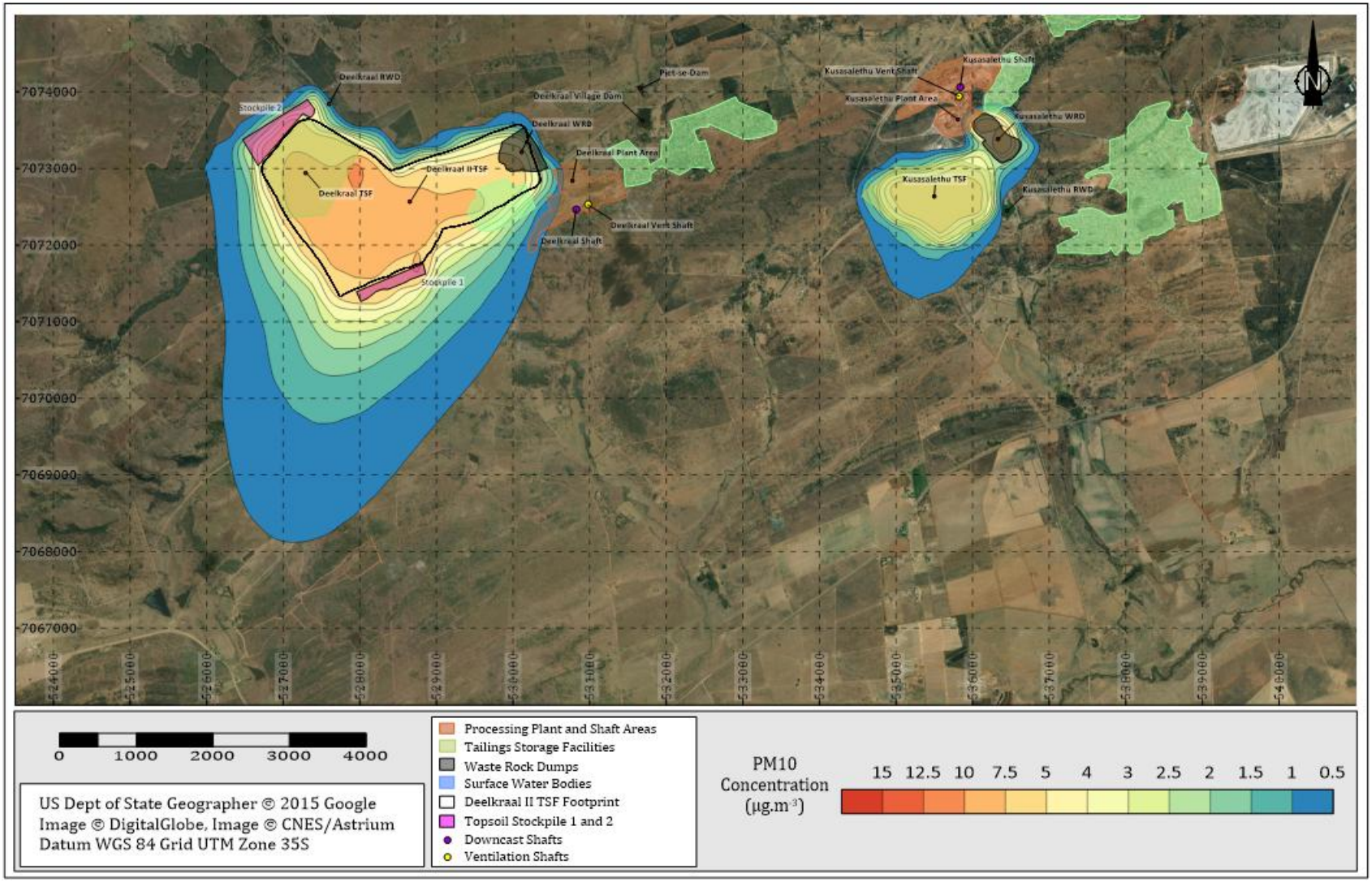


Figure 4.2 The simulated future annual average airborne PM_{10} concentrations (in units of $\mu g.m^{-3}$) attributed to the Project.

According to the modelled data, the highest dust concentrations are associated with the construction of the proposed new Deelkraal II TSF. Figure 4.3 and Figure 4.4 present a similar representation of the maximum daily dust deposition rate (in units of $mg.m^{-2}.day^{-1}$) for all the sources combined.

Figure 4.5 and Figure 4.6 present the predicted current and future activity concentration of radon. The radon dispersion estimate is based on an assumed unit release of radon from the airborne radon pathway sources provided by Airshed. The resulting values were scaled using source-specific radon release rates (e.g., for the WRDs and TSFs). These values are presented in Section 5.

The flow diagram in Figure 4.7 can be used to evaluate the contribution of the atmospheric pathway to a quantitative total effective dose. It follows from the source description in Section 4.3 that airborne radioactivity near the Project can be attributed to emissions of dust containing long-lived alpha-emitting radionuclides (LLα) and radon gas. Note that the airborne contaminant plume will contribute to the external gamma radiation dose (plume immersion), and inhalation of the airborne radioactivity contributes to the inhalation dose.

As shown in Figure 4.7, airborne contaminants may be deposited onto surface soils, resulting in a soil concentration. Depending on prevailing atmospheric conditions, contaminants deposited on the soil may be resuspended, further distributing them in the air. Exposure to the soil concentration also contributes to an external gamma radiation dose (groundshine). Similarly, airborne contaminants may be deposited onto the surface water bodies, contributing to the surface water pathway (see Section 4.4.4). The deposition of airborne contaminants can introduce secondary pathways that may contribute to a total effective dose

The deposition of airborne contaminants can introduce secondary pathways that may contribute to a total effective dose. Of importance is the uptake of radioactive contaminants into the food chain. Several processes influence the transfer of airborne contaminants to crops (including animal feed and human food) as part of the atmospheric pathway:

- Direct deposition and interception of contaminants onto crops;
- Deposition of airborne contaminants onto the soil surface, followed by root uptake of contaminants from the soil (or *vice versa*; biological decay of crops containing radionuclides may increase the soil concentration); and
- Transfer (through translocation) of the deposited contaminants to the plant structure.

Some contaminants will be lost during food preparation, while others will be washed off the plant (contributing to soil concentrations). Contaminants deposited in soil can be taken up by plants, thereby contributing to individuals' annual effective dose when consumed. Animal ingestion of contaminated crops or soil, or inhalation of airborne radioactivity, may lead to contamination of animal products such as dairy, eggs, and meat. Humans who consume affected animals will receive a dose.

Human ingestion of contaminated crops, soil, or animal products, or inhalation of airborne radioactivity, will result in an internal dose. The total effective dose received through the atmospheric pathway is the sum of the individual doses received via ingestion, inhalation, and external gamma exposure.

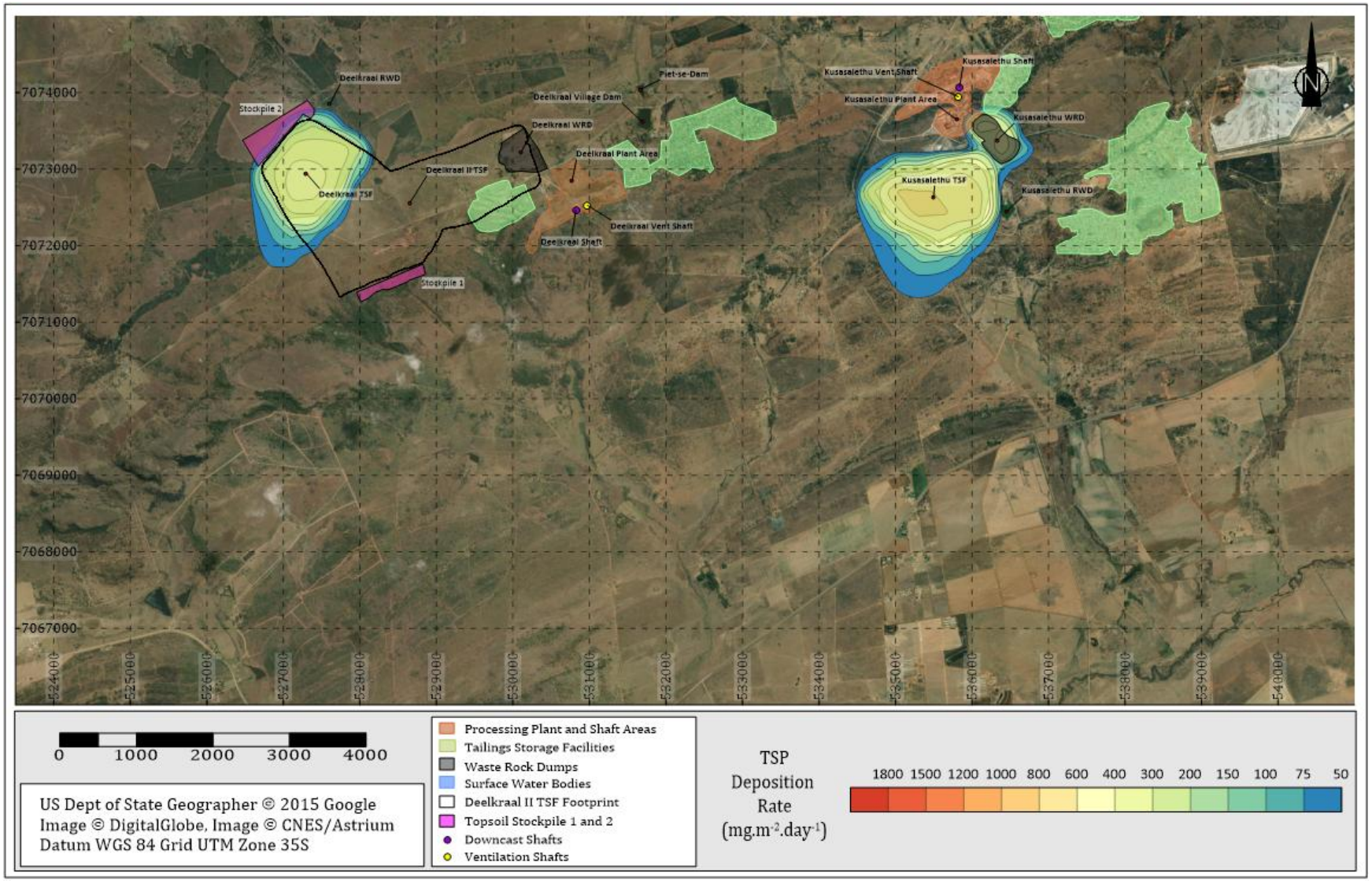


Figure 4.3 The simulated current annual average airborne TSP deposition rate (in units of mg.m^{-2}.day^{-1}) attributed to the Kusasalethu Operations.

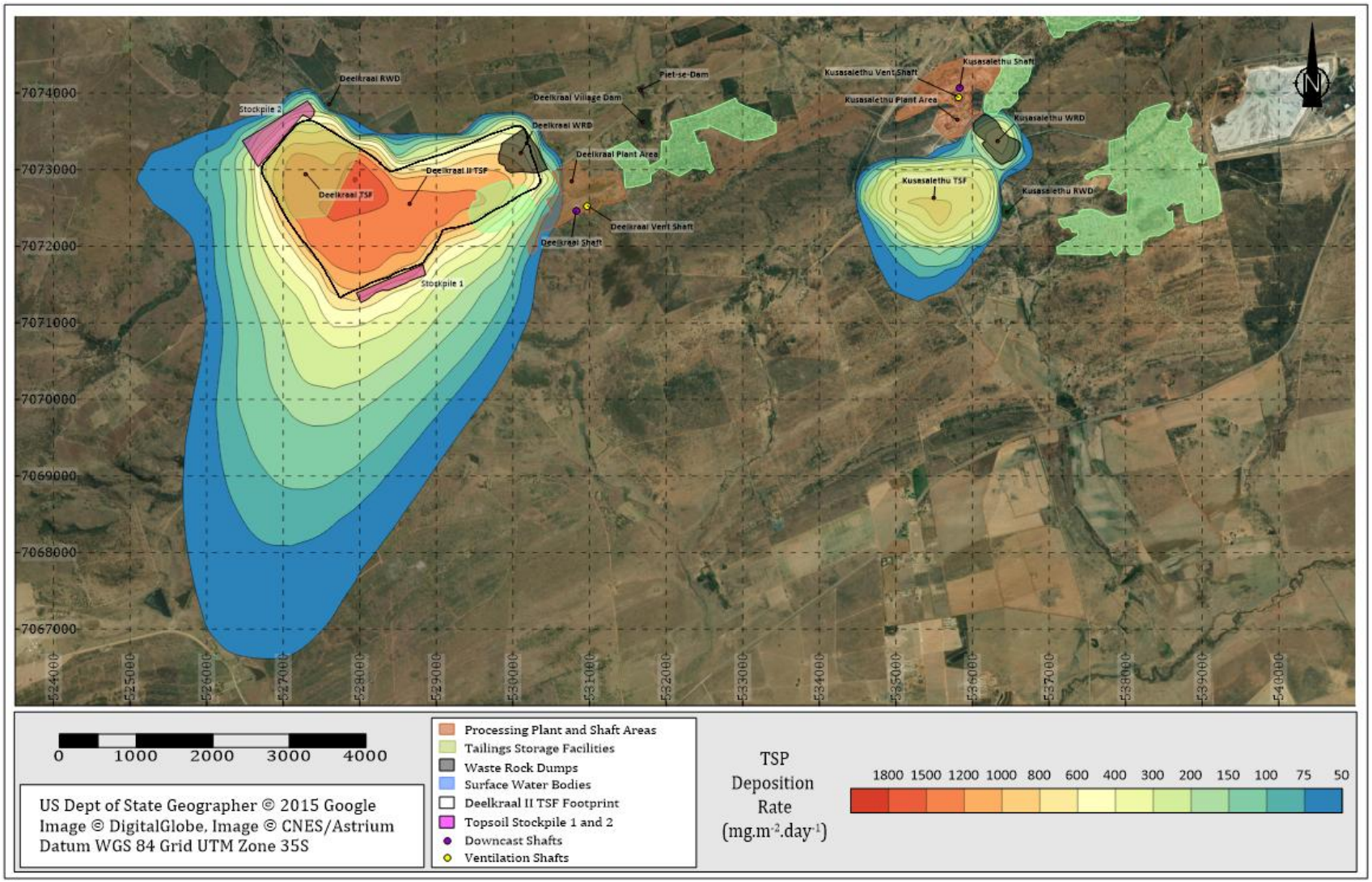


Figure 4.4 The simulated future annual average airborne TSP deposition rate (in units of mg.m^{-2}.day^{-1}) attributed to the Project.

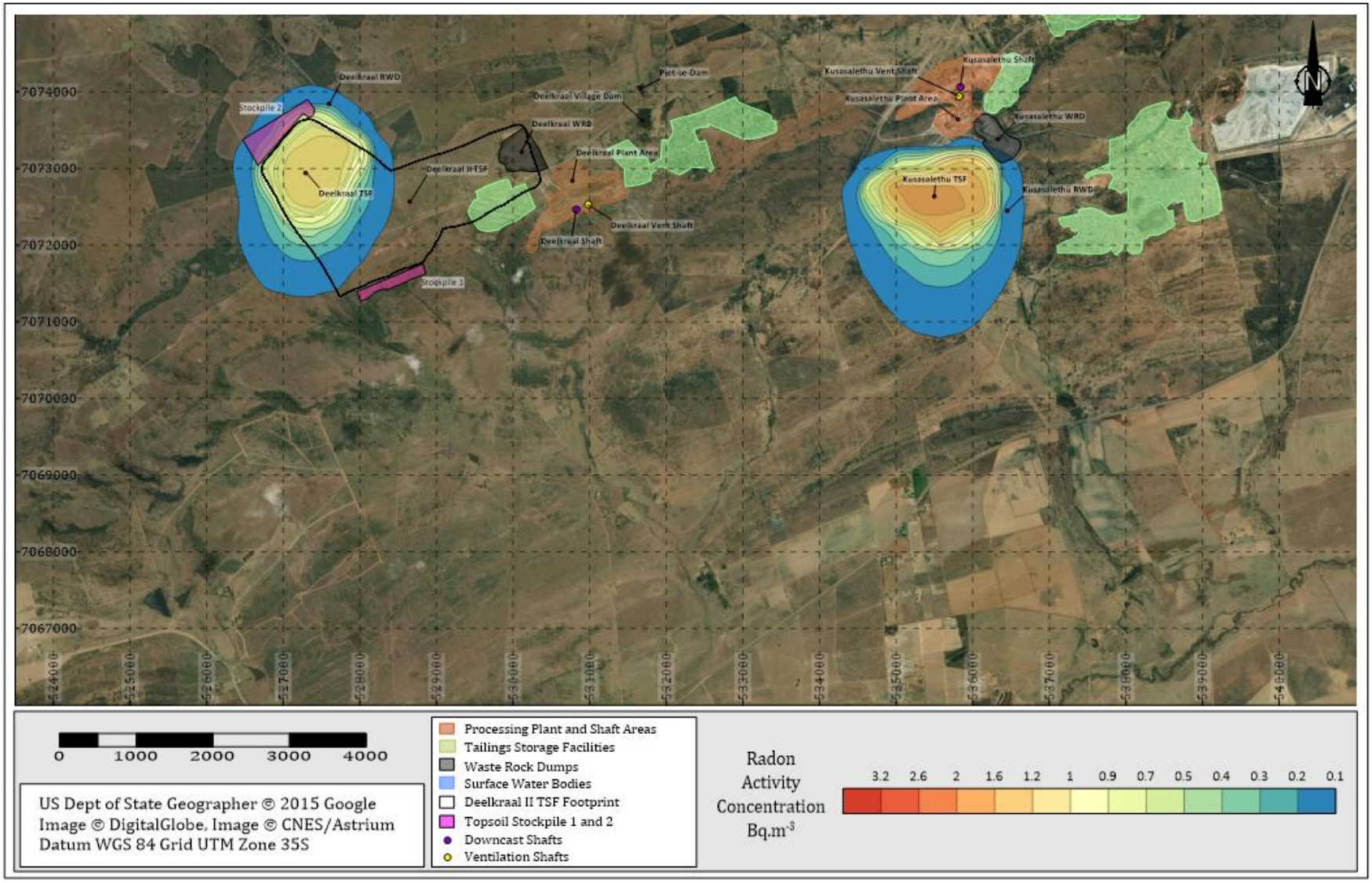


Figure 4.5 The simulated current annual average radon concentration for the Kusasalethu Operations, as derived from data from Airshed (2026).

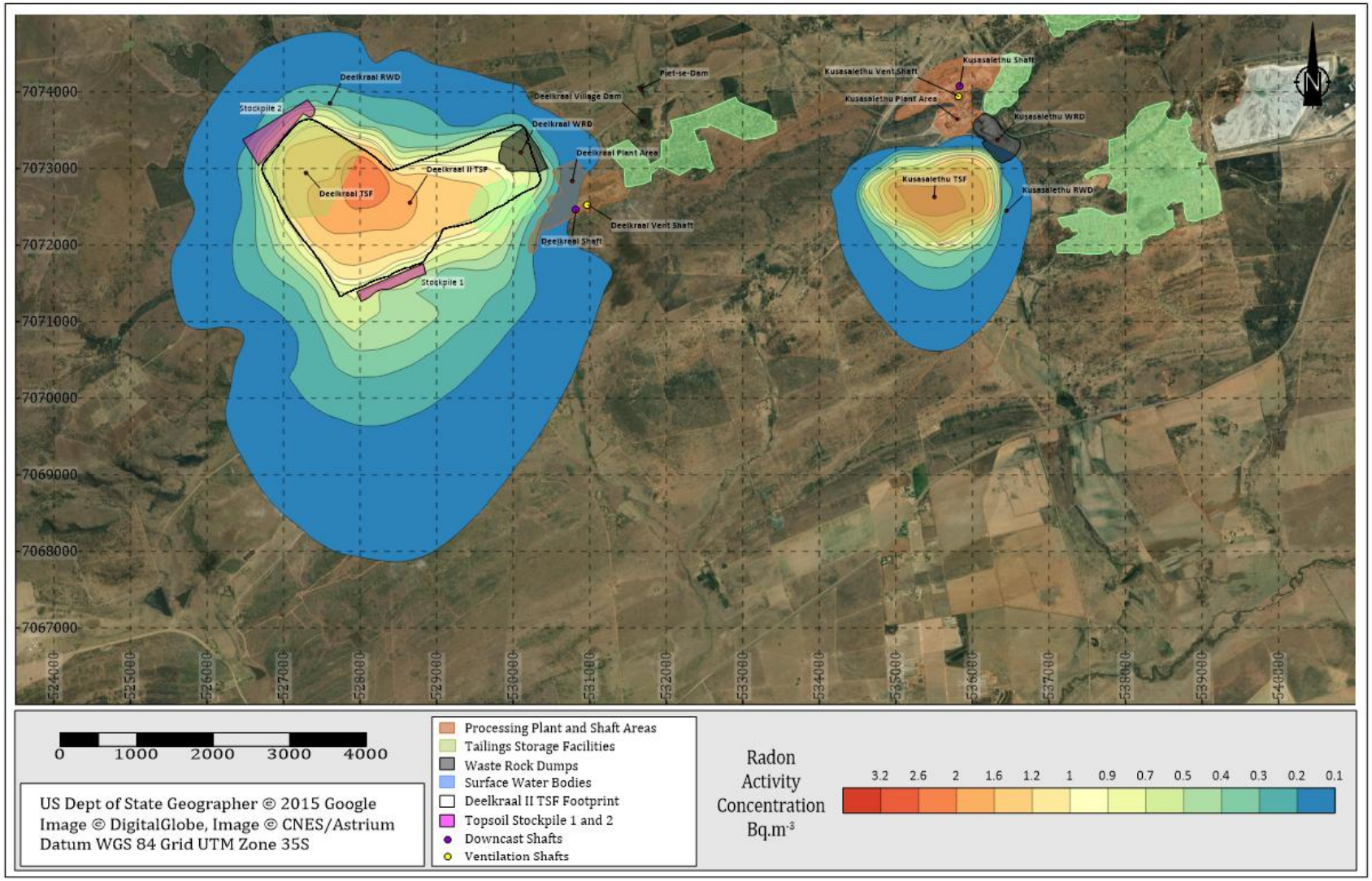


Figure 4.6 The simulated future annual average radon concentration for the Project, as derived from data from Airshed (2026).

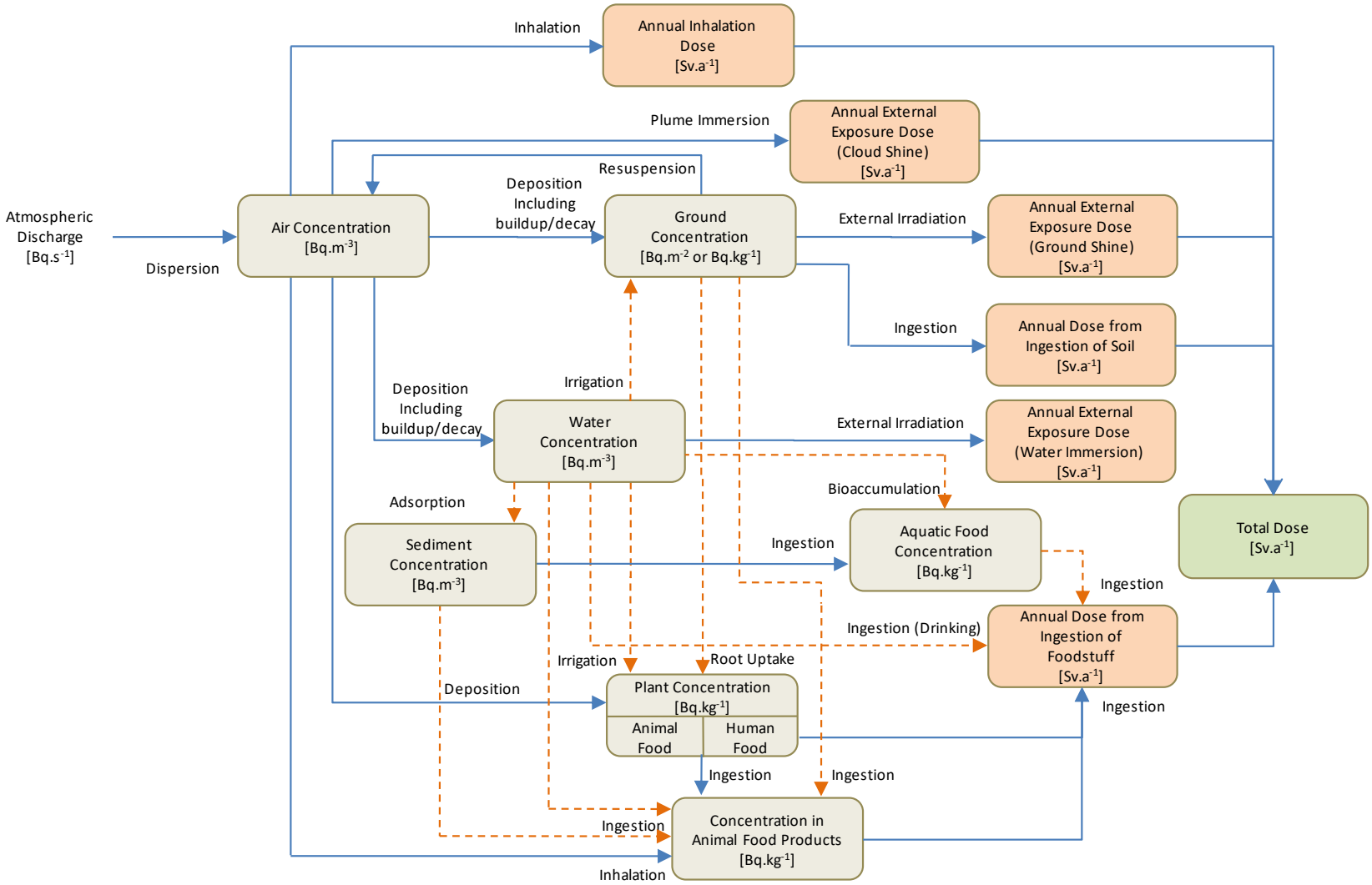


Figure 4.7 **Features, processes, and associated exposure modes to consider when calculating the atmospheric pathway's contribution to the total dose.**

4.4.3 Groundwater Pathway

The primary sources of radiation exposure for the groundwater pathway associated with the Project (see Section 4.3) are the Kusasalethu and Deelkraal TSFs, the proposed new Deelkraal II TSF, the Kusasalethu WRD, the Deelkraal WRD footprint area, and, to a lesser extent, the various water management facilities.

Figure 3.20 to Figure 3.23 show the simulated current and future contaminant (SO_4) plumes from the TSFs and WRDs at the Project. The simulated results indicate how the contaminant plumes may develop (over 50 years) should leachate from these facilities reach the underlying aquifer. To what extent this can occur is a function of the physical and radiological characteristics of the facility itself, and the unsaturated zone between the facility and the underlying aquifer.

It follows from Section 3.6.5 that the unsaturated zone, defined by the depth of the water table (or piezometric head), is 2 to 24 m. Groundwater flow (or moisture movement) in the unsaturated zone is generally very slow, primarily due to the nonlinear relationship between hydraulic conductivity and moisture content. Lower moisture content means slower moisture movement and slower migration of contaminants leaching from the facilities into the unsaturated zone. As in the saturated zone, contaminant migration is further retarded by geochemical processes at the solid-liquid interface. It is thus clear that the groundwater pathway encompasses not only saturated groundwater flow in the underlying aquifer but also the migration of contaminants that leach from facilities through the unsaturated zone. However, the characteristics of the saturated zone and the potential for contaminated groundwater to migrate to receptor locations remain important.

Section 3.6.5 further presents results from a hydrogeological study conducted for the Kusasalethu Operations (MvB Consulting, 2026), which indicated that the groundwater gradients at the Project are towards the surface-water drainage defined by the local streams. Near the Deelkraal TSF, Deelkraal II TSF and Village Dam, drainage is predominantly towards the Wonderfontein Spruit, north of the site. Drainage from the Kusasalethu TSF, Kusasalethu WRD, Deelkraal WRD, and the Kusasalethu return water dam flows towards the Loop Spruit, south of the site. Thus, at a local scale, the Wonderfontein Spruit and the Loop Spruit will serve as potential environmental receptors for contamination originating from the Kusasalethu Operation. The same applies to groundwater abstracted within this zone. However, it should be considered that the contaminant plumes shown in Figure 3.20 to Figure 3.23 are representative of sulphate, which is very soluble and easily remains in solution. The movement of radionuclides may be retarded relative to other contaminants due to geochemical reactions and solubility constraints. Consequently, the radionuclides may take tens of thousands of years to migrate to groundwater discharge points such as boreholes (e.g., monitoring, drinking or irrigation boreholes), fountains, and surface water bodies.

The flow diagram in Figure 4.9 can be used to estimate the contribution of the groundwater pathway to the total effective dose. Varied flow and geochemical processes cause contaminants to leach from various groundwater pathway sources through the unsaturated zone to the underlying aquifer, resulting in groundwater concentrations.

Through groundwater (or moisture) flow and radionuclide transport processes (e.g., advection, dispersion, and diffusion), radionuclides will migrate through the unsaturated and saturated zones to various discharge points (e.g., surface water streams, rivers, dams, springs, or boreholes). This will increase radionuclide concentrations in groundwater at these points. Groundwater movements may be very slow, and geochemical reactions may retard the movement of radionuclides relative to the groundwater flow even further. Consequently, the radionuclides may take tens of thousands of years to migrate to groundwater discharge points such as boreholes (e.g., monitoring, drinking or irrigation boreholes), fountains, and surface water bodies.

Depending on the radionuclide concentration in groundwater and on human habits and behavioural characteristics, various secondary pathways can contribute to the total effective dose, as illustrated in Figure 4.9. These pathways are similar to those described for the atmospheric pathway, except that, instead of deposition of airborne contaminants onto crops or soils, irrigation water contributes to radionuclide concentrations in crops or soils.

4.4.4 Surface Water Pathway

Under normal operational conditions, the surface water pathway extends the groundwater pathway and, to a lesser extent, the atmospheric pathway. However, the controlled or uncontrolled release of contaminated water or mine residue may directly contribute to radiation exposure via the surface-water pathway. Once discharged into the surface watercourse, radionuclides are subject to a series of physical and chemical processes that affect their transport from the point of discharge.

These processes, illustrated in Figure 4.8, include the following (IAEA, 2001):

- Flow processes, such as down-current transport (advection) and mixing processes (turbulent dispersion);
- Sediment processes, such as adsorption/desorption on suspended, shore/beach and bottom sediments, and down-current transport, deposition, and re-suspension of sediment, which adsorbs radionuclides;
- Other processes, including radionuclide decay and other mechanisms that will reduce concentrations in water, such as radionuclide volatilisation (if any).

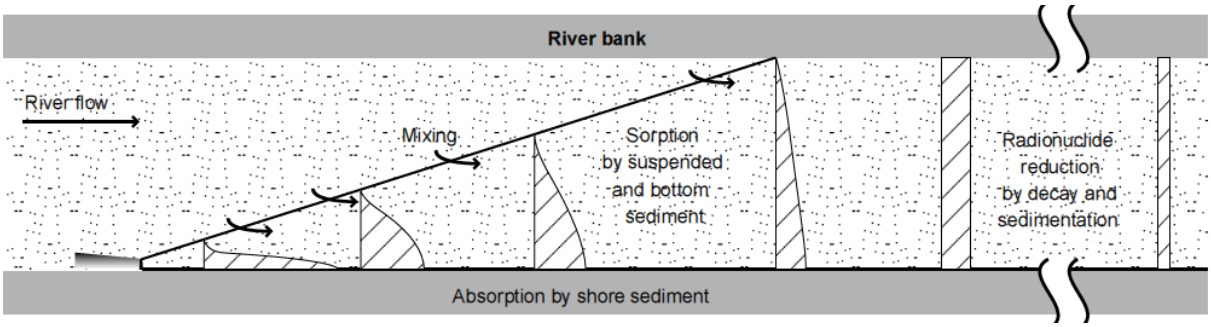


Figure 4.8 Processes affecting the movement of radionuclides from the point of discharge into a surface water body (IAEA, 2001**).**

The distribution of radionuclides into the surface water environment is thus much faster than in groundwater, and large volumes of surface water and sediment can become contaminated. However, the radionuclide concentrations in a surface watercourse may be diluted, depending on the volume of water that will be discharged into the surface watercourse and the volume of water flowing past the point of discharge.

Information presented as part of Section 3.6.3 indicated that surface water in the Deelkraal Dam contains radionuclides. The presented radioanalytical data showed that radionuclide concentrations in the water vary over time and, on average, are significantly higher than those reported in groundwater samples. Surface water is therefore considered a potential pathway for public radiation exposure for the Project RPSA.

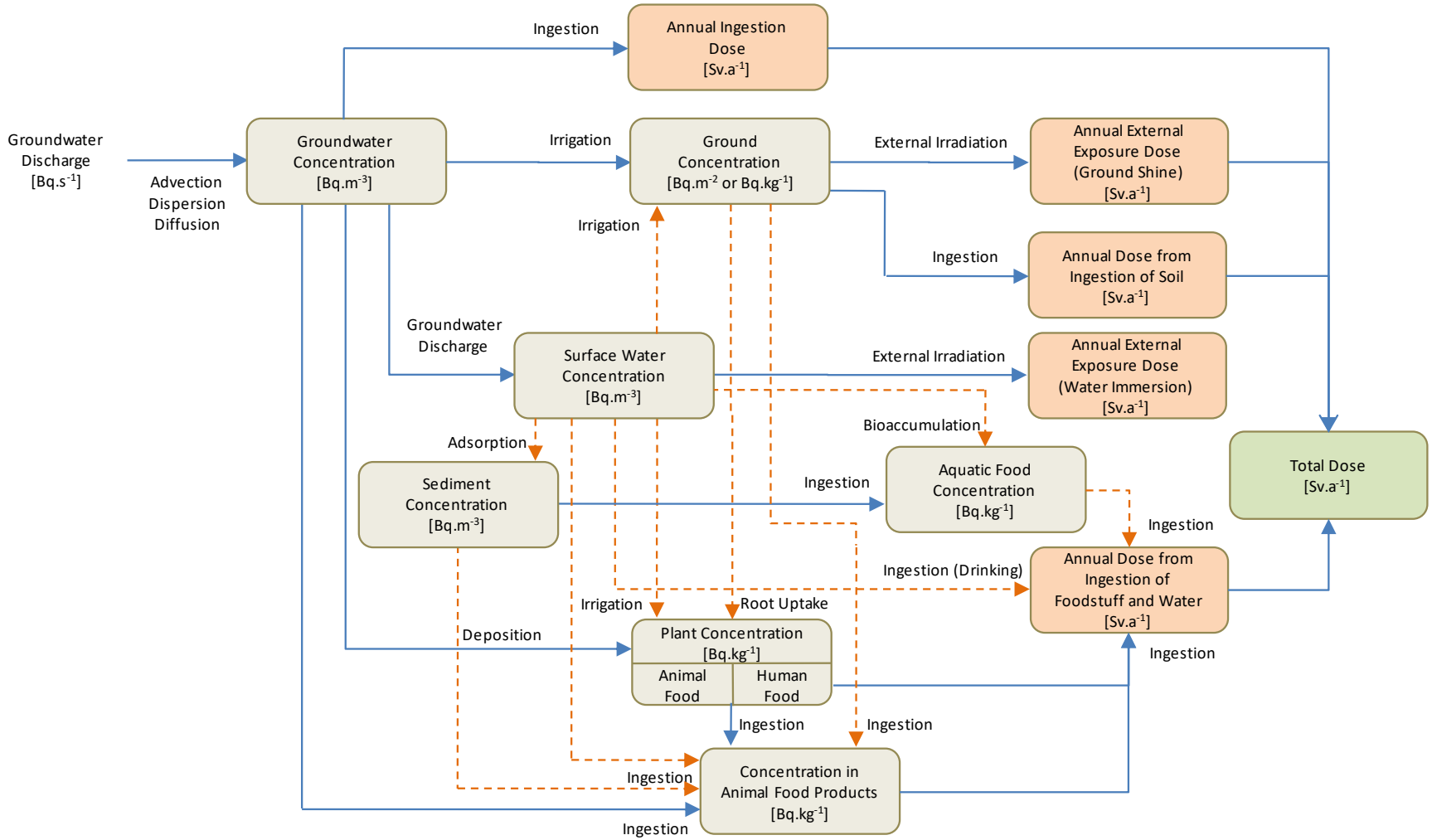


Figure 4.9 **Features, processes, and associated exposure modes to consider when calculating the groundwater pathway's contribution to the total dose.**

The flow diagram in Figure 4.10 can be used to calculate the contribution of the surface-water pathway to the total effective dose. Deposition of airborne radionuclides onto surface water bodies may increase radionuclide concentrations in surface water. Factors that will influence the migration of radionuclides in surface water include surface water/groundwater interaction (e.g., discharge rates), mean annual flow rates, seasonal variation, and adsorption of radionuclides onto sediments.

Depending on the radionuclide concentration in surface water and on human habits and behavioural characteristics, various secondary pathways can contribute to the total effective dose, as illustrated in Figure 4.10. These pathways are similar to those described for the atmospheric pathway, except that, instead of deposition of airborne contaminants onto crops or soils, irrigation with contaminated water increases radionuclide concentrations in crops or soils.

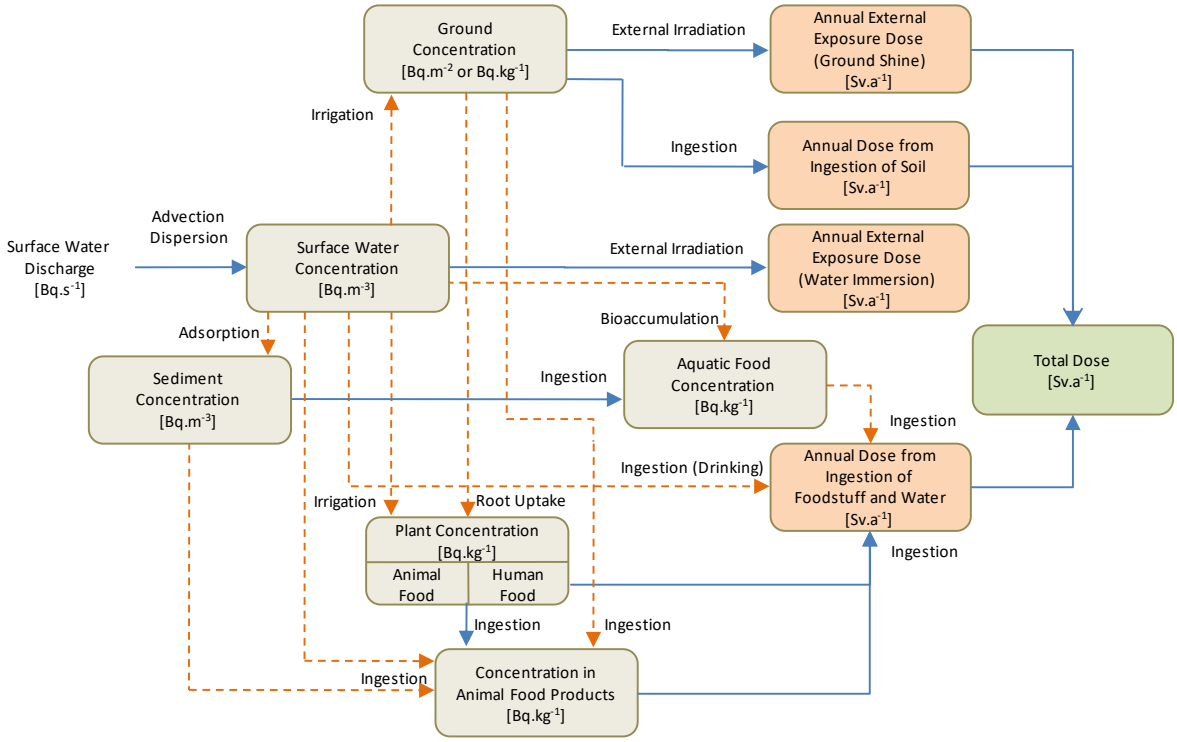


Figure 4.10 Features, processes, and associated exposure modes to consider when calculating the surface-water pathway's contribution to the total dose.

Direct exposure to contaminated surface water (e.g., swimming) also contributes to an external gamma radiation dose (water immersion). Adsorption of contaminants onto sediments will result in their transfer and accumulation (build-up) within the sediments (sediment concentration). Contaminants in surface water can be transferred to aquatic animals such as fish (bioaccumulation) and can also be ingested from contaminated sediments.

4.4.5 External Gamma Radiation

Although not contaminants in the usual sense, the inherent radiological properties of some primary radiation sources may result in continuous gamma radiation, potentially exposing members of the public to external exposure. The external gamma radiation would be highest close to the source, as radiation levels decrease by a factor of the square of the distance (i.e., inversely proportional to the square of the distance) away from the source (Martin, 2006b).

Members of the public can thus only be exposed if they come near the facilities. The main infrastructures that can be associated with external gamma radiation are the tailings storage facilities and any other areas that may be deemed contaminated with residue tailings material. Gamma radiation from releases of contamination to the environment (secondary sources) is expected to be limited.

4.5 Receptors

Receptors, as defined in Section 4.2, are members of the public who could receive a radiation dose from Project-related releases through the relevant exposure pathways. The objective is to identify one or more population groups whose habits, locations, ages, or other characteristics may result in higher doses than those of the broader population that may be exposed. Within the Source–Pathway–Receptor (SPR) framework, this means not only defining contaminant sources and migration pathways but also evaluating local land use and human behaviours. Section 3.7 details land use and activities around the Project, which are critical inputs for assessing potential radiation-exposure risks.

Land use conditions near the Project include residential (peri-urban) and low-density commercial agriculture. Social specialists identified 73 sites near the Kusasalethu Operational area that are likely to be used for residential accommodation, in addition to the three residential communities of Elandsrand, Wedela and Deelkraal. Equispectives (2026) also identified the addition of informal occupiers and subsistence/artisanal users, comprising artisanal miners, cattle herders, and small-scale cultivators, alongside the established farming communities.

Since most of these identified residential sites are located on what seems to be agricultural land, it is conservatively assumed that the buildings are used by farmers or farm workers engaged in agricultural activities. Figure 3.32 indicates the locations of buildings and structures within a 5 km radius of the Project that are situated in the areas potentially affected by the dispersed airborne contaminants indicated in Figure 4.2, Figure 4.3 and Figure 4.5. Viewed from this perspective, the potential receptors considered in the assessment include the residential communities of Elandsrand, Wedela and Deelkraal, as well as a few of the structure locations.

4.6 Timescales

The significance of the sources, pathways, and receptors associated with a specific operation is time-dependent. In other words, their significance as a contributing factor to a public radiation exposure situation may vary during the lifecycle of the mining and mineral processing operation (i.e., from pre-operational to post-operational conditions).

Some of the primary sources of radiation exposure identified for the Project may be terminated at closure. Sources such as TSFs and WRDs may be reclaimed, rehabilitated, and closed in accordance with the prescribed closure plan, while other TSFs may remain sources of radiation into the post-operational period, albeit at a lower level of significance due to rehabilitation. Natural processes will also help reduce potential exposure levels. Processes such as radioactive decay and the leaching of contaminants into deeper layers will reduce source-term release rates from different facilities over long timescales.

Consistent with the requirements of RG-002, the scope of this assessment is limited to the operational period, with some consideration of longer-time processes. However, no assumptions will be made regarding alternative human behavioural conditions and significant operational changes during the post-operational period. No assumptions about institutional control periods (passive or active) are therefore necessary.

The timescales associated with operational activities to induce secondary sources should also be noted. Spillages from pipeline bursts must be reported as incidents. Clean-up operations have to commence and be completed as part of the closeout report. If dealt with in this manner, the potential exposure to members of the public is very limited due to limited timescales.

Material handling and transport activities will only contribute as a secondary source during operations. Controlled and uncontrolled releases of radioactivity to the environment would vary on a case-by-case basis. It could be associated with a relatively short period (until clean-up operations commence) or for the duration of the operations.

4.7 Conceptual Model Development

4.7.1 General

Models representing natural systems are often viewed as comprising two distinct but interconnected components: a *conceptual model* and a *mathematical model*. A conceptual model is expressed by ideas, words, and figures, while a mathematical model is expressed as mathematical equations. The two are closely related and, in essence, the mathematical model results from translating the conceptual model into a mathematical problem that can be solved (NRC, 2003).

It is recognised that in the natural sciences, the term' conceptual model' is applied in diverse ways. Its interpretation and use often depend on the field and purpose of the application. Various definitions of conceptual models can thus be found in the scientific and technical literature. These definitions are consistent in their fundamental meaning and differ mainly in scope, detail and context. The statement of the conceptual model often reflects the key questions to be investigated (NRC, 2003). In its simplest form, a conceptual model is a representation and simplification of reality as seen by the observer or analyst.

As applied in other scientific fields, conceptual models are widely used in radiological public safety assessments. The use of conceptual models in the development of exposure conditions is illustrated in Figure 1.5 and Figure 4.11. The purpose of this section is to clarify their use within the Project RPSA. The associated mathematical models are presented in the *Mathematical Model Development* document compiled by ARP Consulting (2026).

A distinction can be made between the conceptual models used to represent public exposure conditions and those used to represent the different environmental pathways of concern. The use of conceptual models for these pathways as input into the safety assessment process is discussed in Section 4.7.2, while Section 4.7.3 presents an overview of how conceptual models are presented as part of the definition of the different exposure conditions (see Section 4.8).

4.7.2 Conceptual Models for Environmental Pathway Analysis

Three environmental pathways are important in radiological public safety assessments of mining and mineral processing operations: atmospheric, groundwater, and surface water. To a lesser extent, external gamma radiation may also contribute to the total effective dose (see Section 4.4.5).

Specialist studies to quantify the behaviour of some of these environmental pathways have been conducted as part of the ESHIA process for the Project (see Section 3). Conceptual models developed as part of these Process Level studies will not be repeated here.

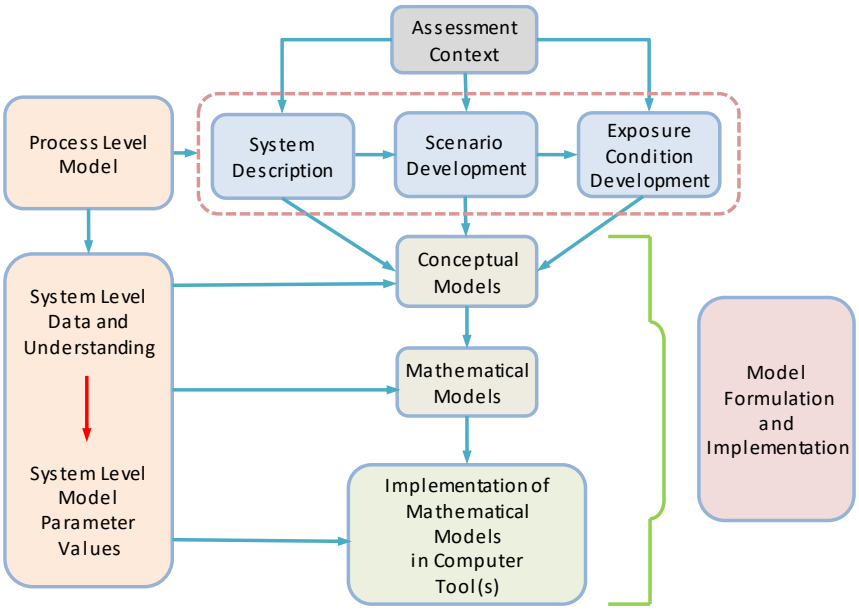


Figure 4.11 **The model development process in relation to other elements of the assessment framework presented in Figure 1.5.**

4.7.3 Representation of Conceptual Models for Exposure Conditions

The conceptual model for developing exposure conditions is a schematic representation of reality intended to enhance the readability, transparency, and traceability of the assessment process. Viewed from this perspective, it may also be regarded as a *conceptual schema* or *conceptual data model*, which is a map of concepts and their relationships. Minor as it may seem, it all contributes to the overall confidence in the assessment process.

Two methods are used to represent the exposure conditions conceptually: a process flow diagram and a RES Matrix or Interaction Matrix (Kozak and Zhou, 1998). In an Interaction matrix, the main variables or parameters are identified and listed along the leading diagonal of a square matrix. The interactions between the parameters occur in the off-diagonal terms. A simple example of a 2x2 matrix is illustrated in Figure 4.12, with the atmospheric (radioactive dust concentration) and topsoil layer as diagonal elements. Deposition represents an interaction between the atmosphere and the surface soil, while some of the deposited dust may be resuspended back into the atmosphere.

It is thus clear that the different elements of the system can be included in the Interaction Matrix and analysed in detail by creating one or more sub-matrices. This approach suggests that a specific theme, such as the radionuclide migration pathway from sources to receptors, can be represented by the elements on the main diagonal. The off-diagonal elements represent the interactions among events and processes that cause or influence the migration of radionuclides from one diagonal element (system feature) to another along the identified pathway. Those above the diagonal represent the influence on the forward motion, while those below influence the backward motion. This is illustrated in Figure 4.13, which depicts a 5x5 matrix and the potential migration pathway of radionuclides from element D to element E via interactions between diagonal and off-diagonal elements.

Figure 4.14 is an example of a flow diagram as a conceptual model, showing the pathway of concern (e.g., atmospheric sources), the exposure pathways, and their relationship through processes with the different components or compartments in the system of concern. Similar to the Interaction Matrix, the transfer of radioactivity from the source to the receptor can be traced.

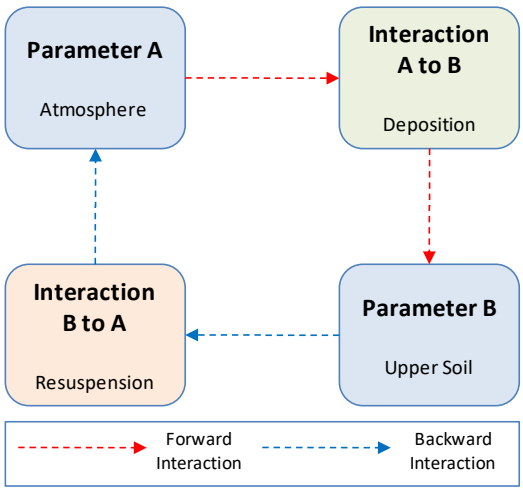


Figure 4.12 **A simple 2x2 Interaction Matrix, showing the interaction between features, events and processes in a safety assessment.**

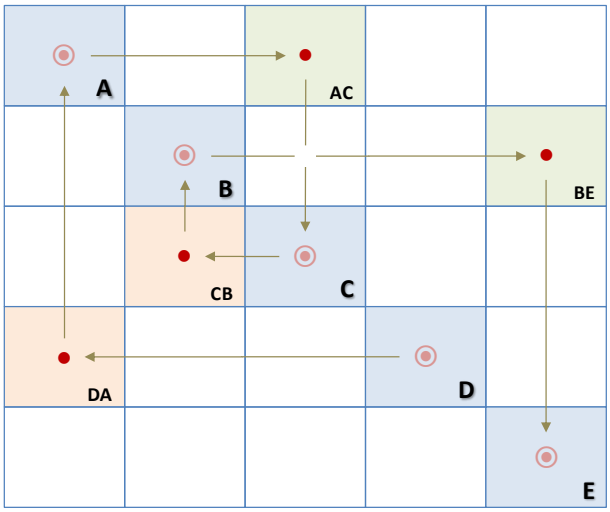


Figure 4.13 **Principle of a radionuclide migration path through the Interaction Matrix.**

4.8 Public Exposure Conditions for the Project

4.8.1 General

It follows from Section 4.3 that several potential sources of radiation exposure are associated with the Project that may contribute to releases to the atmospheric and aquatic pathways. The extent and timescales over which this might happen vary. The release mechanisms (source terms) for the groundwater pathway, for example, tend to be slow. Releases from the atmospheric pathway sources are much faster. Direct releases into the surface-water pathway (e.g., overflow from a water management facility) are often event-specific and may have only a brief impact.

Consistent with the source analysis, the main environmental pathways of concern as identified in Section 4.4 are the atmospheric, surface water and groundwater pathways. The sources will contribute to the atmospheric pathway through the release of particulate matter and radon gas. The dispersion is localised around the Project surface infrastructure and dissipates with distance away from the sources. This impact via the atmospheric pathway will persist as long as the sources remain at the site.

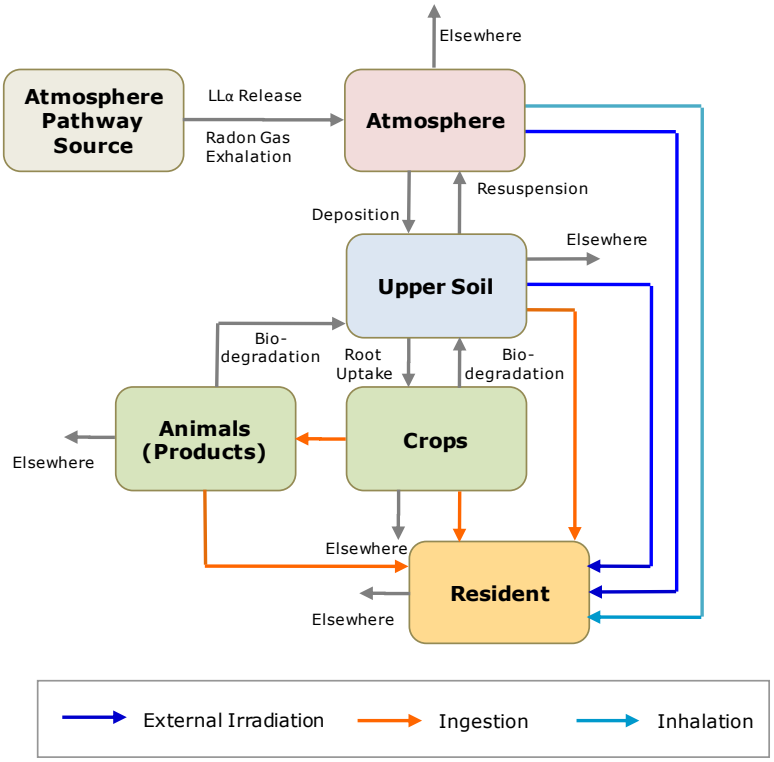


Figure 4.14 A flow diagram is a conceptual model for a specific exposure condition, illustrating the exposure pathways and the relationships among the system's compartments.

The release mechanisms for groundwater pathway sources and the subsequent dispersion into and through the environment differ from those for atmospheric pathways. The groundwater pathway is a slow process, mainly due to radionuclide adsorption onto porous media, with the potential radiological impact occurring only in the far future. The migration path extends through the unsaturated zone (vertically downward) before following the groundwater flow path to the lower-lying areas.

Release mechanisms for surface-water pathway sources include discharging contaminated water into surface-water bodies (e.g., streams). Besides direct releases to surface water resources (e.g., pipeline spills or overflow from a surface impoundment), the surface water pathway is significant only as an extension of the atmospheric pathway (e.g., following deposition) and the groundwater pathway (e.g., following groundwater discharge into a surface water body).

The receptors identified in Section 4.5 are associated with population groups, based on available social and land-use data, whose habits, locations, and other characteristics could lead them to receive a higher radiological dose than the rest of the exposed population. These include the residential communities of Elandsrand, Wedela and Deelkraal, as well as the formal and informal residents of the agricultural land. Note that only receptor locations inside the potential zone of impact from the Project, as defined by the surface water, groundwater and atmospheric pathways, were considered. These groups are assumed to consist of members of the public of all ages.

4.8.2 Criteria Used to Define the Discrete Set of Exposure Conditions

Given the nature of a mining and mineral processing operation, the definition of an exposure condition depends on several factors, such as:

- Different exposure conditions may be important during different phases of the mining and mineral processing operations.
- Exposure conditions may vary with site-specific operational conditions.
- Different sources of radiation exposure (e.g., point or diffuse sources) may lead to different exposure conditions for receptors.
- The importance of environmental (e.g., atmospheric, surface water, or groundwater) or direct exposure pathways depends on source characteristics and human behavioural characteristics.
- Variations in human behavioural conditions near the mining and mineral processing operation may result in different exposure conditions of concern.

Understandably, defining all exposure conditions for every potential radiation-exposed receptor at a mining and mineral processing operation is impossible, especially when evaluating potential radiological consequences. For this reason, the approach is to revert to a limited number of exposure conditions that capture the environment's diversity and complexity. While the SPR analysis approach systematically derives exposure conditions, expert judgment may still be needed to combine information on sources, pathways, and receptors into well-defined, justified exposure conditions. The following criteria are used for this purpose:

- Consistent with the ICRP principles, the radiological protection of each member of the public is of paramount importance. However, it is impractical to derive an exposure condition for each individual. The emphasis, therefore, is on defining exposure conditions that are representative of a wide range of individuals and human behavioural conditions.
- In doing so, the emphasis is also on defining exposure conditions that are representative of the group with the highest exposure, without implying that other exposed groups are less important.
- To the extent possible, actual conditions are considered to derive exposure conditions that are representative and realistic.

Where justified, a set of alternative and more hypothetical exposure conditions is defined. These hypothetical conditions tend to be more conservative, allowing a wide range of conditions to be postulated. Often, these exposure conditions would be representative of the most exposed individual, albeit hypothetical. The key point in judging whether the discrete set of exposure conditions is representative for radiological public safety and impact assessment is whether potential radiation-exposed receptors can be associated with at least one of these exposure conditions.

4.8.3 Definition and Justification of Public Exposure Condition for the Project Area

Based on the selected receptor groups listed in Section 4.8.1 and the criteria presented in Section 4.8.2, the following exposure conditions are considered to evaluate the radiological public impact and safety of the Project:

- A Residential Area Exposure Condition; and
- A Commercial Agricultural Exposure Condition.

In principle, several additional exposure conditions can be defined that are equally relevant to the area and the nature of the Project. These include exposure conditions considered typical of an area dweller, an industrial worker, or a mine hostel resident, for example. However, as will be illustrated and discussed in Section 6, the potential exposure to these groups would be lower than for the Residential Area Exposure condition. It can be evaluated as part of a sensitivity analysis by varying parameter values. An explicit evaluation is, therefore, not necessary.

4.8.3.1 Residential Area Exposure Condition

The purpose of the Residential Area Exposure Condition is to evaluate the radiological consequences to members of the public living in residential areas in all directions near the Project, some of which fall within the atmospheric pathway dispersion plumes. Residents of these areas can be further divided into those living in formal and informal structures. However, it follows from the *System Description* (see Section 3.7) that, in terms of potential radiological exposure, their behavioural characteristics are not markedly different, particularly regarding what they eat. The main differences lie in their socio-economic structures. These differences (e.g., occupancy factors, time spent indoors and outdoors, shielding factors) could be catered for using sensitivity analysis (parameter variation).

One can assume that members of the public residing in residential areas may have household gardens to supplement their daily food supply. However, it is reasonable to expect that informal settlements might be more dependent on these food sources and therefore include more crops, such as mealies. It is also reasonable to expect that they keep livestock, such as chickens, cattle, and goats, to supplement their daily protein requirements (eggs, milk, and meat). However, residents in formal areas generally have access to plots of land large enough to meet their annual food needs, whereas residents in informal areas generally do not.

The main contributor to the total effective dose in residential areas was found to be atmospheric (i.e., ambient air) and associated secondary pathways. No evidence was presented to suggest that any residents in the informal settlements have access to a groundwater supply point, and there are no surface water resources near enough to the areas to indicate that surface water could be utilised. It is thus assumed that members of informal residential areas are supplied with water by the local municipality.

Routes of radiological exposure for members of the Residential Area Exposure Condition include external gamma radiation, internal exposure from ingestion of contaminated soil, crops, and animal products, and internal exposure from inhalation of airborne radon and LLα dust. In addition to the conditions and assumptions presented above, the following are assumed for the Residential Area Exposure Condition:

- The exposure groups consist of members of the public from all age groups.
- The exposure group maintains a small household garden consisting of fruits, vegetables (leafy and root), and cereal (mealies), which fulfils 50% of their annual requirements for these foods.
- The exposure group keeps animals, including chickens, goats, and cattle. These serve as sources of protein, including eggs, milk, and meat. For the assessment, it is conservatively assumed to contribute 50% of their daily protein intake.
- Food preparation (e.g., peeling, boiling) may reduce radioactivity concentrations in fruits and vegetables. However, for this assessment, it is assumed that radionuclide concentrations in any food produced in the area remain the same regardless of the preparation method used.
- Consistent with RG-002 guidelines (NNR, 2013), Table 4.3 lists the age-group-specific indoor and outdoor occupancy factors used for the assessment.
- As a conservative assumption, the rate of incidental soil ingestion is maintained at 100% of the value published in RG-002 (NNR, 2013).

Table 4.3 Age group-specific indoor and outdoor occupancy factors (NNR, 2013).

Activity	0 to 2 Years	2 to 7 Years	7 to 12 Years	12 to 17 Years	Adult
Time spent indoors	7,914	7,775	7,568	7,665	7,050
Time spent outdoors	846	985	1,192	1,092	1,710

The conceptual model for the Residential Area Exposure Condition is presented in Figure 4.15 and Figure 4.16 using a flow diagram and an Interaction Matrix, respectively.

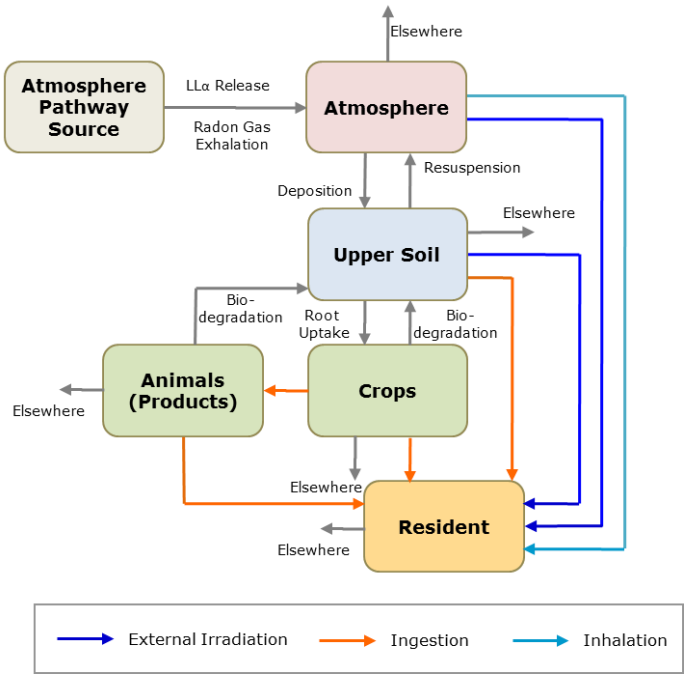


Figure 4.15 **Conceptual flow diagram of the exposure pathways associated with a Residential Area Exposure Condition.**

	1	3	4	6	7	8	9	10
A	Atmospheric Pathway Sources	LLα Suspension Dispersion	Radon Exhalation Dispersion					
C		Atmosphere LLα Conc.		Deposition	Deposition Interception		Inhalation External Exposure	Dispersion
D			Atmosphere Radon Conc.				Inhalation	Dispersion
F		Re-suspension		Upper Soil	Root Uptake Crop Contam.	Ingestion	External Exposure Ingestion	Erosion Leaching
G				Bio-degradation	Crops	Ingestion	Ingestion	Washed Away Weathering
H				Bio-degradation Excrement		Animals	Ingestion	
				Irrigation Tilling Ploughing	Plant crops Food preparation	Feed	Resident	Excrement
J								Elsewhere

Figure 4.16 **Conceptual Interaction Matrix of the exposure pathways associated with Residential Area Exposure Condition.**

Radon gas and LLα released from atmospheric sources are dispersed into the environment, thereby increasing airborne radionuclide concentrations. Some airborne radionuclides are deposited on the upper soil surface and on crops (fruits, vegetables, and cereals), increasing radionuclide concentrations in soil and crops. Root uptake processes transfer some radionuclides from the soil to crops. Exposure routes associated with the Residential Area Exposure Condition include radon gas and LLα inhalation, as well as ingestion of contaminated crops (fruits, vegetables, and cereals) and animal products (meat, eggs, and milk). Inadvertent soil ingestion is also assumed. Contributions to the total effective dose from external gamma radiation are also expected from airborne LLα (cloud immersion) and from radionuclides deposited in the upper soil layer (groundshine).

Note that, as illustrated in Figure 4.15 and Figure 4.16, biodegradation of crop material may also contribute to the upper soil concentration. In contrast, resuspension of deposited dust may contribute to the airborne activity concentration. Also illustrated in Figure 4.15 and Figure 4.16 is the transfer of some of the radioactivity released from atmospheric pathway sources to “elsewhere” through processes such as dispersion, leaching, washing, weathering and excretion. “Elsewhere”, as used here, refers to a place where humans will not be affected by the radionuclides of concern.

4.8.3.2 Commercial Agricultural Exposure Condition

The purpose of the Commercial Agricultural Exposure Condition is to evaluate the radiological consequences to members of the public living and practising commercial farming anywhere in the vicinity of the Project. Based on the human behavioural conditions presented in Section 3.7, the exposure condition relates to any agricultural activities in the area, including crop farming (fruit, leafy, and root vegetables) and livestock farming (cattle, sheep, and chickens). This means that the exposure condition applies to any commercial farming activity, including smallholdings and community gardens, under the conditions and assumptions presented below. It is assumed that the exposure groups included in the Commercial Agricultural Exposure Condition comprise members of the public across all age groups.

The main contributors to the total effective dose for the Commercial Agricultural Exposure Condition are atmospheric, groundwater, and associated secondary pathways. Groundwater is used to sustain the farm system through irrigation and the supply of water to livestock. In addition to the conditions and assumptions presented above, the following are assumed for the Commercial Agricultural Exposure Condition:

- The exposure groups consist of members of the public from all age groups.
- The exposure group maintains a farm system consisting of fruits and vegetables (leafy and root), which fulfils 100% of their annual fruit and vegetable consumption.
- As a conservative assumption, the rate of incidental soil ingestion is maintained at 100% of the values presented in RG-002 (NNR, 2013).
- Some food preparation methods (e.g., peeling or boiling) may reduce radioactivity concentrations in fruits, vegetables, or reared poultry. However, for this assessment, it is assumed that no food preparation takes place.
- The indoor and outdoor occupancy factors assumed for the assessment are those presented in RG-002 (NNR, 2013): 7,050 and 1,710 hours per annum for adult members of the public, respectively.
- The exposure condition assumes a 75-year TSP deposition period, which is conservative given the area's history of mining activities.

The conceptual model for the Agricultural Exposure Condition is presented in Figure 4.17 and Figure 4.18 using a flow diagram and an Interaction Matrix, respectively.

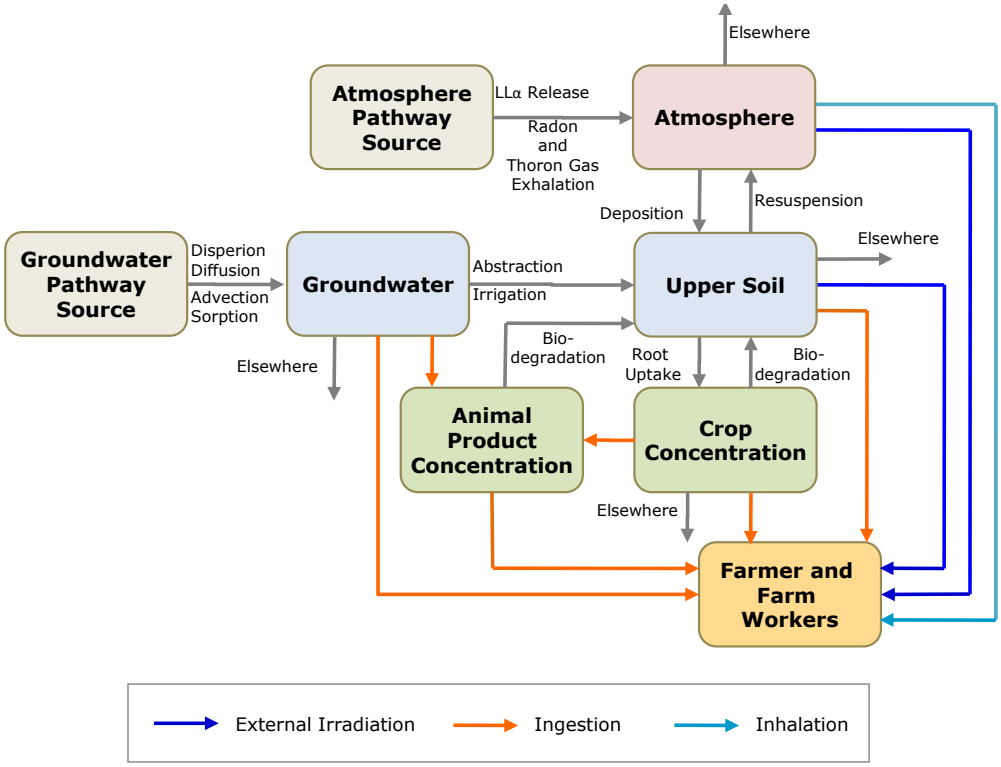


Figure 4.17 Conceptual flow diagram of the exposure pathways associated with the Commercial Agricultural Exposure Condition.

Exposures associated with the atmospheric pathway are similar to those discussed for the Residential Area Exposure Condition. Some airborne radionuclides are deposited onto the upper soil surface, contributing to soil radionuclide concentrations. Root uptake processes transfer some radionuclides from the soil to crops in the field or household garden, as well as to grass consumed by cattle.

The concentration of radionuclides in the upper soil will steadily increase over time as more and more dust-containing radionuclides are deposited from the air. Note that, as illustrated in Figure 4.17 and Figure 4.18, biodegradation of plant material (such as crops, animal fodder or grazing) may also contribute to the concentration of radionuclides in the upper soil, while re-suspension of deposited dust may contribute to the airborne activity concentration. Physical processes, such as soil mixing from tilling, will redistribute radioactive elements and resuspend deposited dust, which may contribute to airborne activity concentrations.

Humans, in this case, represented by the yellow block labelled ‘Commercial Farmer’ in Figure 4.17, may be exposed to radioactivity distributed through atmospheric and aquatic pathways via inhalation, ingestion, and external exposure routes.

Irrigation with contaminated groundwater or surface water contributes to contamination of the upper soil layers and to its distribution via associated secondary pathways (e.g., crops and animal products). Backwards interactions redistribute the radioactivity initially introduced through the water pathways within the upper soil and to the atmospheric pathway. The distribution and redistribution of contaminants originating from atmospheric and water pathways, as well as the exposure associated with the Commercial Agricultural Exposure Condition, are illustrated in the flow diagram shown in Figure 4.17.

	1	2	3	4	5	6	7	8	9	10
A	Atmospheric Pathway Sources		LLα Suspension Dispersion	Radon Exhalation Dispersion						
B		Groundwater Pathway Sources			Advection Dispersion Diffusion Sorption					
C			Atmosphere LLα Conc.			Deposition	Deposition Interception		Inhalation External Exposure	Dispersion
D				Atmosphere Radon Conc.					Inhalation	Dispersion
E					Water (Borehole)	Deposition	Interception	Ingestion	Ingestion	Advection Dispersion Diffusion Sorption
F			Re-suspension			Upper Soil	Root Uptake Crop Contamination.	Ingestion	External Exposure Ingestion	Erosion Leaching
G						Bio-degradation	Crops	Ingestion	Ingestion	Washed Away Weathering
H						Bio-degradation Excrement		Animals	Ingestion	
					Abstract	Irrigation Tilling Ploughing	Plant crops Food preparation	Feed	Farmer and Farm Worker	Excrement
J										Elsewhere

Figure 4.18 Conceptual Interaction Matrix of the exposure pathways associated with the Commercial Farming Exposure Condition.

Animals that consume grass ingest a portion of dust or soil along with the plant material they take in. The radioactivity in the upper soil can therefore also contribute to radionuclide contamination of animal products. The expected exposures associated with each route include:

- Inhalation of radon gas and dust containing LLα;
- Ingestion of contaminated produce (fruit, leafy and root vegetables) picked from gardens (100% annual consumption rate);
- Inadvertent ingestion of contaminated soil;
- External exposure to radionuclides deposited in the upper soil layer (ground shine); and
- External exposure to airborne LLα (cloud shine).
- Ingestion of contaminated water,
- External exposure to contaminated water (bathing); and

Ingestion of contaminated produce irrigated with contaminated water.

5 Consequence Analysis

5.1 Introduction

The purpose of the consequence analysis is to assess the potential radiological consequences of the public exposure conditions defined for the Project in Section 4.8.3. Consistent with the safety assessment framework and technical approaches therein (see Figure 1.5), the assessment results are then interpreted in terms of the total annual effective dose as compliance criteria (boundary conditions) as defined in the *Assessment Context* (see Section 2).

The section is structured as follows. Section 5.2 evaluates the potential contribution of the groundwater pathway. Section 5.3 evaluates the contribution of the atmospheric pathway included in the definition of the Residential Area Exposure Condition. In comparison, Section 5.3.7 then evaluates the radiological consequences of the Residential Area Exposure Conditions defined in Section 4.8.3 in terms of the total effective dose.

5.2 Contribution from Groundwater Pathway

5.2.1 General

While the use of groundwater is not included in the definition of the Residential Area Exposure Condition, the use of groundwater as a source of water for some residents cannot be excluded with confidence. In principle, groundwater abstracted from a borehole may be contaminated by leachate from facilities associated with the Project (e.g., TSF or RWD). However, due to associated retardation processes, leaching and subsequent lateral migration of radionuclides are slow. The reason is that the radionuclides migrate at a much slower rate than the advective flow due to isotope-specific adsorption properties of the tailings materials and the underlying aquifer host medium.

5.2.2 TSF Conceptual Model and Implementation

The hydrogeological flow regime was described in Section 3.6.5. It follows from Section 4.3.3 that two existing TSFs will be reprocessed, with one TSF proposed to be constructed as part of the Project. This TSF may be a source of radiation exposure via the groundwater pathway. The radiological properties of these facilities will differ, as will the mechanisms for releasing contaminated water into the underlying aquifer (i.e., the source-term release rate to the aquifer). However, once released, contaminant migration processes are similar (e.g., advection, dispersion, diffusion).

To evaluate the contribution of the groundwater pathway, assumptions were made for illustrative purposes. A simplified one-dimensional numerical groundwater model, using a compartmental modelling approach, represents the migration and fate of contaminants in the environment, with a TSF as the source of contamination. Some of the TSFs at the Project will remain a potential source of contamination during the operational and post-closure periods. The conceptual representation of the System Level compartmental model implemented in AFRY Intelligent Scenario Modelling (Version 8.5) (https://www.intelligentscenariomodelling.com/) (AFRY ISM) is described in ARP Consulting (2026).

The groundwater pathway comprises several compartments that must be considered together to assess their potential contribution to the total effective dose. Figure 5.1 depicts the relevant compartments and their interactions. Figure 5.2 presents the AISM implementation of Figure 5.1, which can be used to evaluate the contribution of the groundwater pathway.

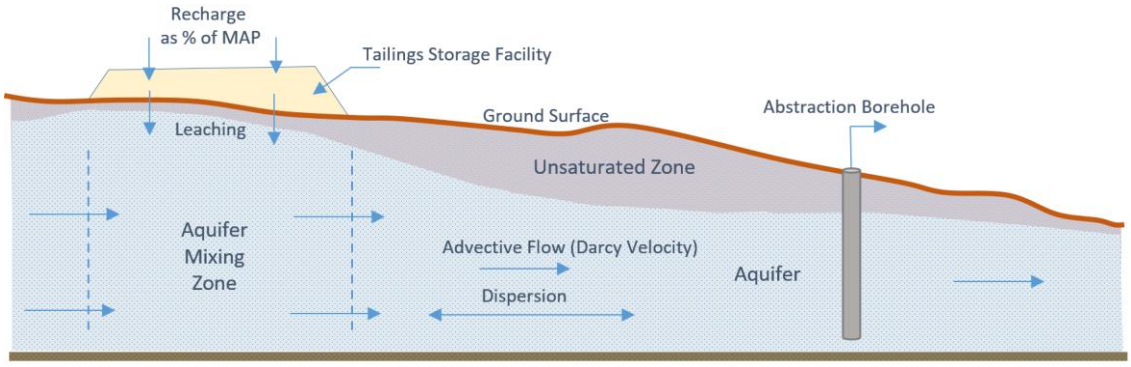


Figure 5.1 **Conceptual representation of the model compartment included in the System Level modelling of the groundwater pathway (Not to Scale).**

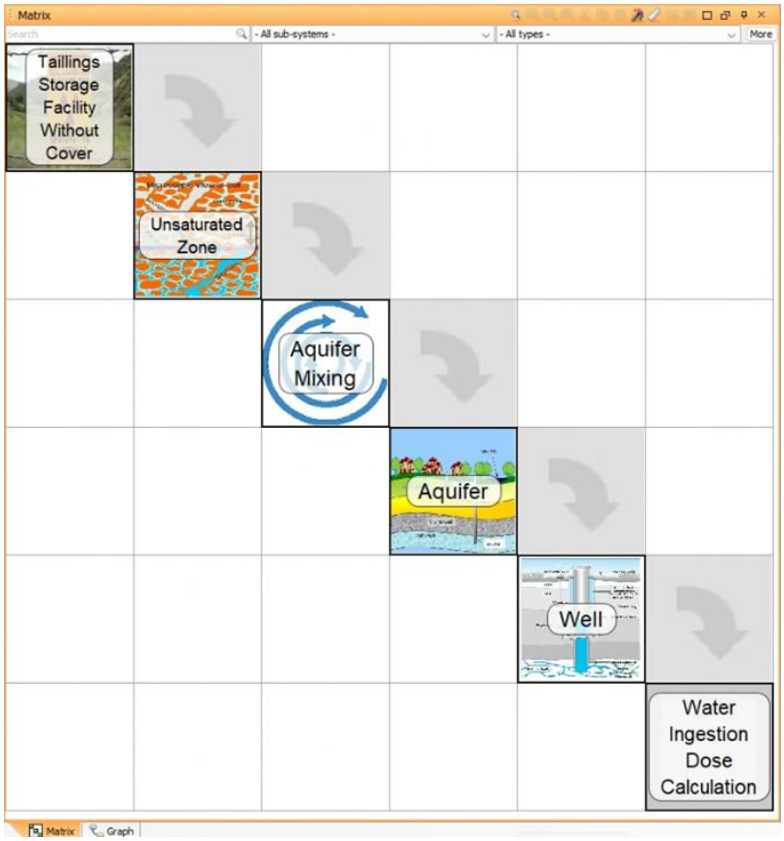


Figure 5.2 **Screen capture of the model implementation in AFRY ISM used to evaluate the contribution of the groundwater pathway for the Project.**

5.2.3 Parameter Values

To evaluate the potential radionuclide concentration in groundwater and the subsequent ingestion dose, hypothetical conditions were complemented with site-specific conditions to illustrate the relative insignificance of the groundwater pathway over a brief period (e.g., the operational period). Table 5.1 lists the activity concentration of the tailings material considered in the analysis. The activity concentrations used reflect an average of the Deelkraal and Kusasalethu samples as given in Section 3.8.2, as reprocessed tailings from both facilities are planned for deposition on the proposed Deelkraal II TSF. Note that modelling of the respective Deelkraal TSF and Kusasalethu TSF is discussed in AquiSim (2023), and will therefore not be repeated here.

Table 5.1 Summary of the activity concentrations relevant to the Deelkraal II TSF.

Radionuclide	Kusasalethu Tailings	Deelkraal Tailings	Deelkraal II TSF
	Activity Concentrations ($Bq.kg^{-1}$)		
U-238	484	377	430.5
U-234	518	381	449.5
Th-230	518	381	449.5
Ra-226	517	545	531
Pb-210	586	682	634
Po-210	586	682	634
U-235	22	17	19.5
Pa-231	22	17	19.5
Ac-227	22	17	19.5
Th-232	37	41	39
Ra-228	47	49	48

The activity concentrations of radionuclides in the decay chains not presented were estimated assuming secular equilibrium between parent radionuclides and their progeny. The following assumptions were consequently applied to the radioanalytical data available for the Project:

- Po-210 = Pb-210 = Ra-226 = Th-230 = U-234 = U-238.
- Ra-223 = Ac-227 = Pa-231 = U-235.
- Th-228 = Ra-228 = Th-232.

Table 5.2 summarises additional parameter values used for the leaching analysis. Note that these parameter values are selected to be conservative.

Table 5.2 Summary of facility-specific parameter values necessary to calculate the leaching of radionuclides from the Deelkraal II TSF.

Parameter		Units	Deelkraal II TSF
Mean Annual Precipitation (MAP)		[mm]	640
Recharge (Infiltration) Rate Through TSF as % of MAP	< 50 years	$[m.y^{-1}]$	9.6E-02 (15% of MAP)
	50 to 75 years		6.4E-02 (10% of MAP)
	75 to 100 years		3.2E-02 (5% of MAP)
	> 100 years		1.92E-02 (3% of MAP)
Volumetric Moisture Content		$[m^3.m^{-3}]$	3.0E-01
The density of Tailings Material		$[kg.m^{-3}]$	1.400E+03
Average Height		[m]	65
Average Area		$[m^2]$	4.3E+06
Assumed Length and Width ($\sqrt{}$Area)		[m]	2.07E+03
Volume		$[m^3]$	2.80E+08

It was assumed that the recharge (or infiltration) rate of water through the TSF decreases over time after the assumed 50-year operational period, reaching a natural recharge rate of 3% of the MAP. It is further assumed that the TSF remains a surface source for 1,000 years. The assumption is conservative, given the uncertainty about how long the Deelkraal II TSF will remain at the surface. However, it is more realistic to assume the TSF will remain at the surface for 1 million years, the duration used in the simulations.

The most sensitive parameters in the TSF radionuclide leaching equation are the distribution coefficient (or K_d-value) and the solubility limits. Low K_d values were used as distribution coefficients for the TSF, unsaturated zone, and aquifer. The assumption is very conservative, assuming minimal absorption to retard radionuclide migration through the system. For this assessment, no solubility limits were applied, which implies that all activity in the tailings is available for dissolution and leaching. *In practice, this is not the case and represents a very conservative approach*.

The approach adopted in the analysis presented here is to use conservative Kd ranges from the literature for illustrative purposes. Table 5.3 lists soil distribution coefficients for selected radionuclides published in RG-002 (NNR, 2013), along with the literature ranges for different soil types reported by the Argonne National Laboratory (Yu *et al.*, 1993). The comparison shows that reported distribution coefficients can vary significantly.

Table 5.3 Distribution coefficients from literature for the elements of concern, as well as the K_d values in the analysis for illustrative purposes (NNR, 2013; Yu *et al.*, 1993).

Element	RG-002	Comparative Values				K_d-values Used
		Sand	Loam	Clay	Resrad Default	
	K_d-values ($m^3.kg^{-1}$)					
Th	1.90E+00	3.20E+00	3.30E+00	5.80E+00	6.00E+01	2.00E-01
Ra	2.50E+00	5.00E-01	3.60E+01	9.10E+00	7.00E-02	3.00E-01
U	2.00E-01	3.50E-01	1.50E-02	1.60E+00	5.00E-02	2.00E-02
Pb	2.00E+00	2.70E-01	1.60E+01	5.50E-01	1.00E-01	2.70E-01
Po	2.10E-01	1.50E-01	4.00E-01	3.00E+00	1.58E+00	1.50E-01
Pa	2.00E+00	5.50E-01	1.80E+00	2.70E+00	5.00E-02	5.50E-01
Ac	1.70E+00	4.50E-01	1.50E+00	2.40E+00	2.00E-02	4.50E-01

Table 5.4 lists additional aquifer parameters needed for the calculations. The unsaturated zone underneath the TSF is conservatively assumed to be only 5 m thick, with a dry bulk density of 1,400 $kg.m^{-3}$ and a volumetric moisture content of 0.3 $m^3.m^{-3}$. A thicker unsaturated zone will retard the migration of radionuclides to the point of abstraction even further. Assuming an effective porosity of 0.05 (5%), an average hydraulic conductivity in the order of 0.085 $m.day^{-1}$ and a hydraulic gradient of 0.02, the actual groundwater flow velocity is 3.4E-02 $m.day^{-1}$. Using these values, the advective potential plume migration rate would be in the order of 1.24E+01 $m.year^{-1}$ for the area as listed in Table 5.2.

Table 5.4 Aquifer parameters assumed for the TSFs and areas of concern to calculate the advective flow and migration of radionuclides.

Parameter	Units	Deelkraal II TSF
Depth to Water Table	m	5
Aquifer Thickness		20
Hydraulic Conductivity	$m.day^{-1}$	8.50E-02
Effective Porosity	-	0.05 (5%)
Hydraulic Gradient		0.02
Darcy Velocity	$m.day^{-1}$	1.70E-03
Actual Velocity		3.40E-02
Longitudinal dispersivity (α_L)	m	50
Dry Bulk Density	$kg.m^{-3}$	1,800
Distance to Borehole	m	500

5.2.4 Results

5.2.4.1 Deelkraal II TSF

The Deelkraal II TSF mainly drains towards the south, with some migration towards the west to existing drainage lines (see Figure 3.22). Here the hydraulic gradient is in the order of 2% (or 0.02), while the hydraulic conductivity in the weathered aquifer can be set at 8.5E-02 $m.day^{-1}$, which equates to a relatively low Darcy velocity of 1.7E-03 $m.day^{-1}$ or 6.21E-01 $m.year^{-1}$ (see Table 5.4). With an effective porosity of 5%, the advective flow velocity is about 12.5 $m.year^{-1}$. Figure 5.3 presents the resulting nuclide-specific activity concentrations in the groundwater abstracted from the borehole. The initial peak concentration is only visible after 60,000 years (the Th-232 decay chain only becomes visible after 600,000 years).

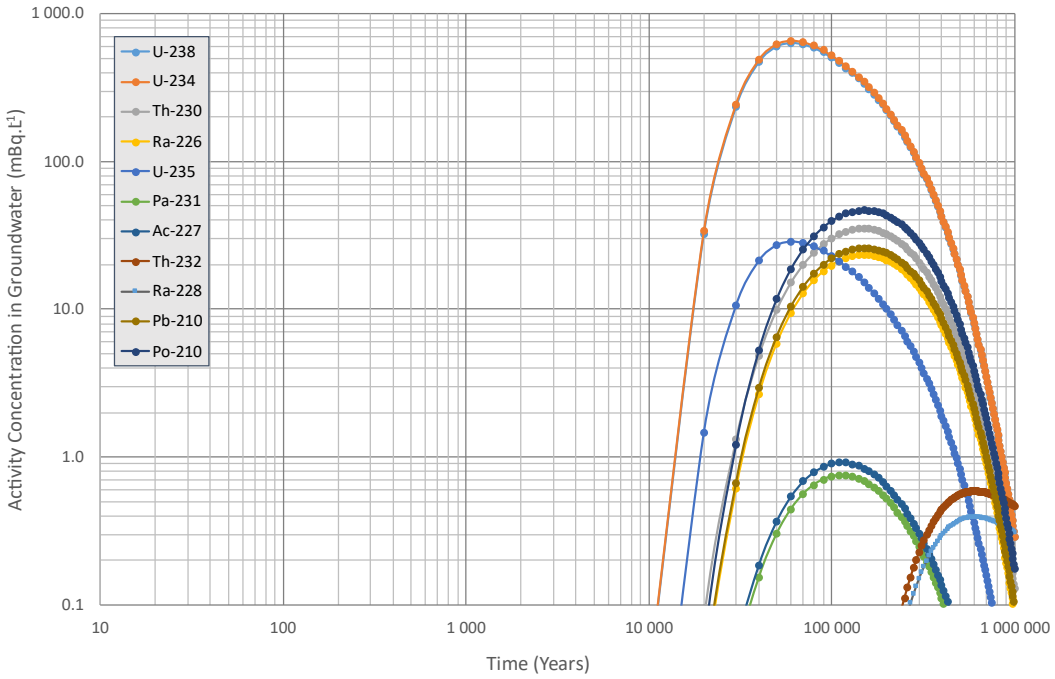


Figure 5.3 **The simulated activity concentration in groundwater abstracted from a borehole 500 m from the Deelkraal II TSF.**

If one assumes the RG-002 (NNR, 2013) water ingestion rates for the different age groups, the groundwater activity concentrations in Figure 5.3 translate to water ingestion doses shown in Figure 5.4. It illustrates that, under the assumed conditions, the contribution from the groundwater pathway at a borehole 500 m from the Deelkraal II TSF is detectable only after 15,000 years, with a peak at approximately 150,000 years and doses less than 160 µSv.year^{-1}.

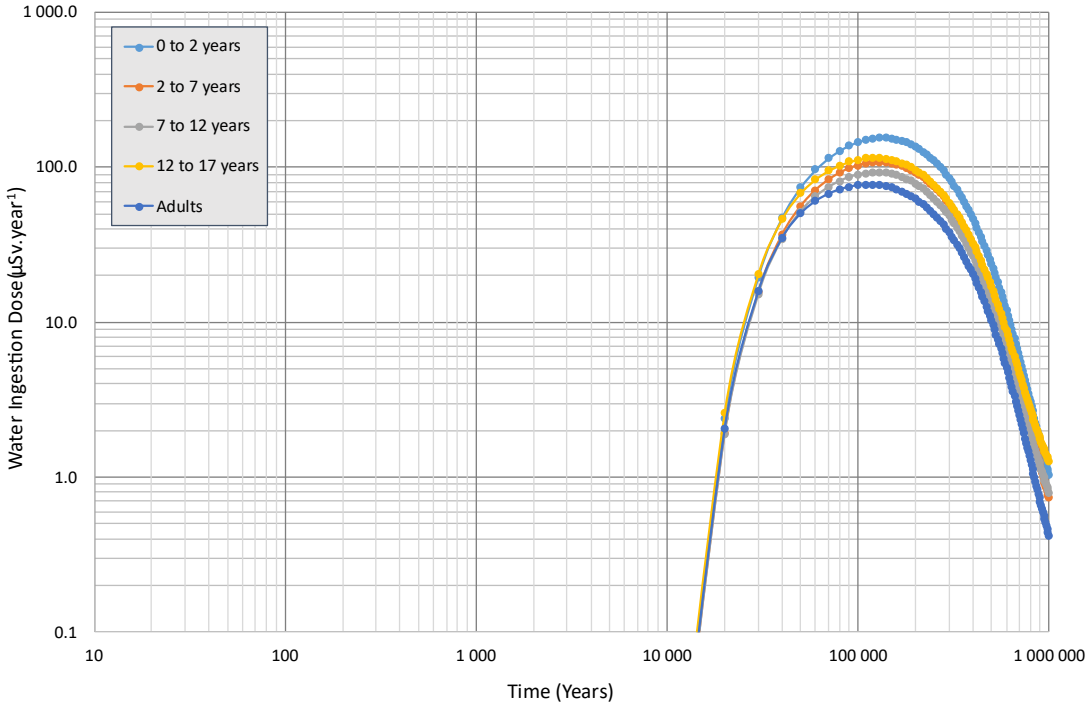


Figure 5.4 **The simulated water ingestion dose to the different age groups 500 m from the Deelkraal II TSF, using the activity concentrations in Figure 5.3.**

5.2.5 Discussion of Results

The *System Level* modelling results presented here for the groundwater pathway are largely for illustrative purposes. They are based on very conservative assumptions to demonstrate the potential radiological impact on members of the public who consume groundwater abstracted from a borehole located 500 m from the Deelkraal II TSF, in the general direction of flow.

Variations are expected as site and facility-specific conditions vary. Higher activity concentration, for example, will result in higher doses, while a higher Darcy velocity (i.e., higher hydraulic conductivity) will reduce the peak dose and the time of maximum. Furthermore, less conservative distribution coefficients (K_d-values) such as the RG-002 values in Table 5.3 will reduce doses, with peak concentrations occurring later. However, it is unlikely that groundwater leached from the TSF and migrated downgradient will contribute to the total effective dose within 10,000 years, even with the conservative set of parameter values. The maximum doses calculated under the assumed conditions are less than 200 μSv.year^{-1}.

The use of natural water resources in the areas surrounding the Project was considered in the development of exposure conditions presented in the *Definition and Justification of Public Exposure Conditions* (see Section 4.8). Groundwater was assumed to be the only source of water for the Commercial Agricultural Exposure Condition. However, the results suggest that the groundwater pathway is unlikely to make a significant contribution to the total effective dose, at least not within the next 10,000 years, and then only at less than 200 μSv.year^{-1}.

The same applies to surface water bodies that receive discharges of contaminated groundwater, which will be further diluted. It is thus reasonable to assume that the aquatic pathway will not make a significant contribution to the total effective dose under the exposure conditions defined for the Project RPSA. However, to demonstrate the potential impact of the aquatic pathway on public exposure, it will be re-evaluated as part of the uncertainty analysis (see Section 6.2).

5.3 Dose Contribution from the Atmospheric Pathway

5.3.1 General

The purpose of this section is to present the results of the total effective dose calculations for the public exposure condition defined for the Project in Section 4.8. Given the nature of the exposure conditions and the potential contributions of different environmental pathways to the total effective dose, the results presented here focus on the atmospheric pathway. The results depend on the sources of airborne contaminants associated with the atmospheric pathway, as well as on the radioactivity concentrations in airborne and deposited dust. The dose contribution presented here is in terms of LLα dust inhalation, radon gas inhalation, the contribution of cloud shine and ground shine (following deposition) to external gamma radiation, as well as the ingestion of crop and animal products at rates as defined for each exposure condition.

5.3.2 Radionuclide Concentration in Airborne and Deposited Dust

The airborne dust concentrations (PM_{10} and TSP) presented in Section 4.4.2 represent the consolidated concentrations from all atmospheric pathway sources of concern. These sources have different radiological properties, meaning that the radioactivity concentrations of the dust released from each source differ.

The radioanalytical results available for the Project are presented in Section 3.8. The activity concentration of other radionuclides in the decay chains not included in the radioanalysis results is estimated assuming secular equilibrium[2] between parent radionuclides and their progeny. The following assumptions were consequently applied to the radioanalytical data available for the Project:

- Po-210 = Pb-210 = Ra-226 = Th-230 = U-234 = U-238.
- Ra-223 = Ac-227 = Pa-231 = U-235.
- Th-228 = Ra-228 = Th-232.

The nuclide-specific activity concentrations estimated for the airborne dust released from the three TSFs are listed in Table 5.5. Multiplication of the radionuclide specific activity concentrations with the PM_{10} (in units of $\mu g.m^{-3}$) and TSP (in units of $mg.m^{-2}.year^{-1}$) concentrations presented in Table 5.5 results in nuclide-specific airborne activity concentrations (in units of $Bq.m^{-3}$) and deposition rate estimates (in units of $Bq.m^{-2}.day^{-1}$). The resulting nuclide-specific airborne concentrations and deposition rates can then be used in the dose assessment calculations.

Table 5.5 Summary of the nuclide-specific activity concentrations of tailings and waste rock samples available for the Kusasalethu Operations (AquiSim, 2023).

Radionuclide	Kusasalethu Tailings	Deelkraal Tailings	Kusasalethu Waste Rock	Deelkraal Waste Rock	Deelkraal II TSF
	Activity Concentrations ($Bq.kg^{-1}$)				
U-238	484	377	19.7	59.7	430.5
U-234	518	381	19.9	60.3	449.5
Th-230	518	381	19.9	60.3	449.5
Ra-226	517	545	22.2	63.1	531
Pb-210	586	682	22.2	168.5	634
Po-210	586	682	22.2	168.5	634
U-235	22	17	0.9	2.8	19.5
Pa-231	22	17	0.9	2.8	19.5
Ac-227	22	17	0.9	2.8	19.5
Th-232	37	41	11	13.5	39
Ra-228	47	49	14.1	12.5	48

5.3.3 Radon Exhalation Rate

Site-specific radon exhalation rates for the surface infrastructure associated with the Project are not currently available. As an alternative, empirical equations derived from numerous site-specific radon exhalation rates across many tailings samples can be used to estimate the radon exhalation rates for the material samples listed in Table 5.5. The equations and coefficients used for deriving radon exhalation rates from tailings are as follows (Parc Scientific, 2006):

Average: Radon exhalation rate ($Bq.m^{-2}.s^{-1}$) = (0.000554 ±0.0000014) x Ra-226 ($Bq.kg^{-1}$)

Minimum: Radon exhalation rate ($Bq.m^{-2}.s^{-1}$) = (0.000376 ±0.000043) x Ra-226 ($Bq.kg^{-1}$)

Maximum: Radon exhalation rate ($Bq.m^{-2}.s^{-1}$) = (0.000609 ±0.0000017) x Ra-226 ($Bq.kg^{-1}$)

[2] *Secular equilibrium is a steady state condition of equal activities between a long-lived parent radionuclide and its short-lived daughter, which is applied to estimate nuclide concentrations in the absence of radioanalytical data. The criterion upon which secular equilibrium depends is given in L'Annunziata (1998).*

Table 5.6 lists the average, minimum and maximum radon exhalation rates estimated from the measured radium concentration in the relevant surface infrastructure listed in Table 5.5. Note that the minimum radon exhalation rate was used for the waste rock samples, in line with AquiSim (2023).

Table 5.6 Estimated average and maximum radon exhalation rates for the surface facilities listed in Table 5.5 associated with the Project area.

Project Facility	Average	Minimum	Maximum
	$Bq.m^{-2}.s^{-1}$		
Kusasalethu Tailings	0.287	0.194	0.315
Deelkraal Tailings	0.302	0.205	0.332
Kusasalethu Waste Rock	0.012	0.008	0.013
Deelkraal Waste Rock	0.035	0.024	0.038
Deelkraal II TSF	0.0294	0.200	0.323

5.3.4 Radon Inhalation Dose

The radon inhalation dose is based on the airborne radon concentration presented in Section 4.4.2 (see Figure 4.5 and Figure 4.6). Figure 5.5 and Figure 5.6 present the resulting current and future radon inhalation doses using the dose conversion factors listed in ARP Consulting (2026). Figure 5.5 and Figure 5.6 show that the radon inhalation dose is most closely associated with the Project facilities and decreases in a southerly direction away from the facilities. The maximum radon inhalation dose outside the boundary is low, at approximately 30 $\mu Sv.year^{-1}$.

5.3.5 LLα Inhalation Dose

Figure 4.1 and Figure 4.2 present the current and future annual-average PM_{10} concentrations. Multiplying these dust concentrations by the relevant activity concentrations in Table 5.5 and the dose conversion factors yields the current and future dust inhalation dose to the adult members of the public, as presented in Figure 5.7 and Figure 5.8. As expected, the inhalation dose distribution is consistent with the PM_{10} distribution shown in Figure 4.1 and Figure 4.2. The maximum dust inhalation dose outside the boundary is extremely low, at a maximum of around 6 $\mu Sv.year^{-1}$.

5.3.6 External Gamma Radiation

The potential contribution of external gamma radiation (cloudshine) to the total effective dose is driven by the PM_{10} dust cloud. Generally, these values are insignificantly small (less than 1 $\mu Sv.year^{-1}$) when PM_{10} concentrations typical of mining and mineral processing activities are observed. In this area, where airborne activity concentrations are low, the contribution of cloudshine to the total effective dose is essentially zero (less than 1.1E-5 $\mu Sv.year^{-1}$). Similarly, the deposition of TSP in the environment and the subsequent accumulation of radionuclides may contribute to external gamma radiation (groundshine). These values depend on the deposition period. Typically, these values are insignificant at the deposition rates and periods (assumed to be 75 years) typical of most mining and mineral processing activities. However, due to the higher concentrations associated with TSP (see Figure 4.3 and Figure 4.4), the annual average external gamma radiation dose from groundshine is also higher than expected.

Figure 5.9 and Figure 5.10 present the current and future annual average external gamma radiation dose from groundshine, with the dose reaching approximately 35 $\mu Sv.year^{-1}$ near the Deelkraal II TSF footprint, indicating that heavier dust particles are dispersed from this facility footprint.

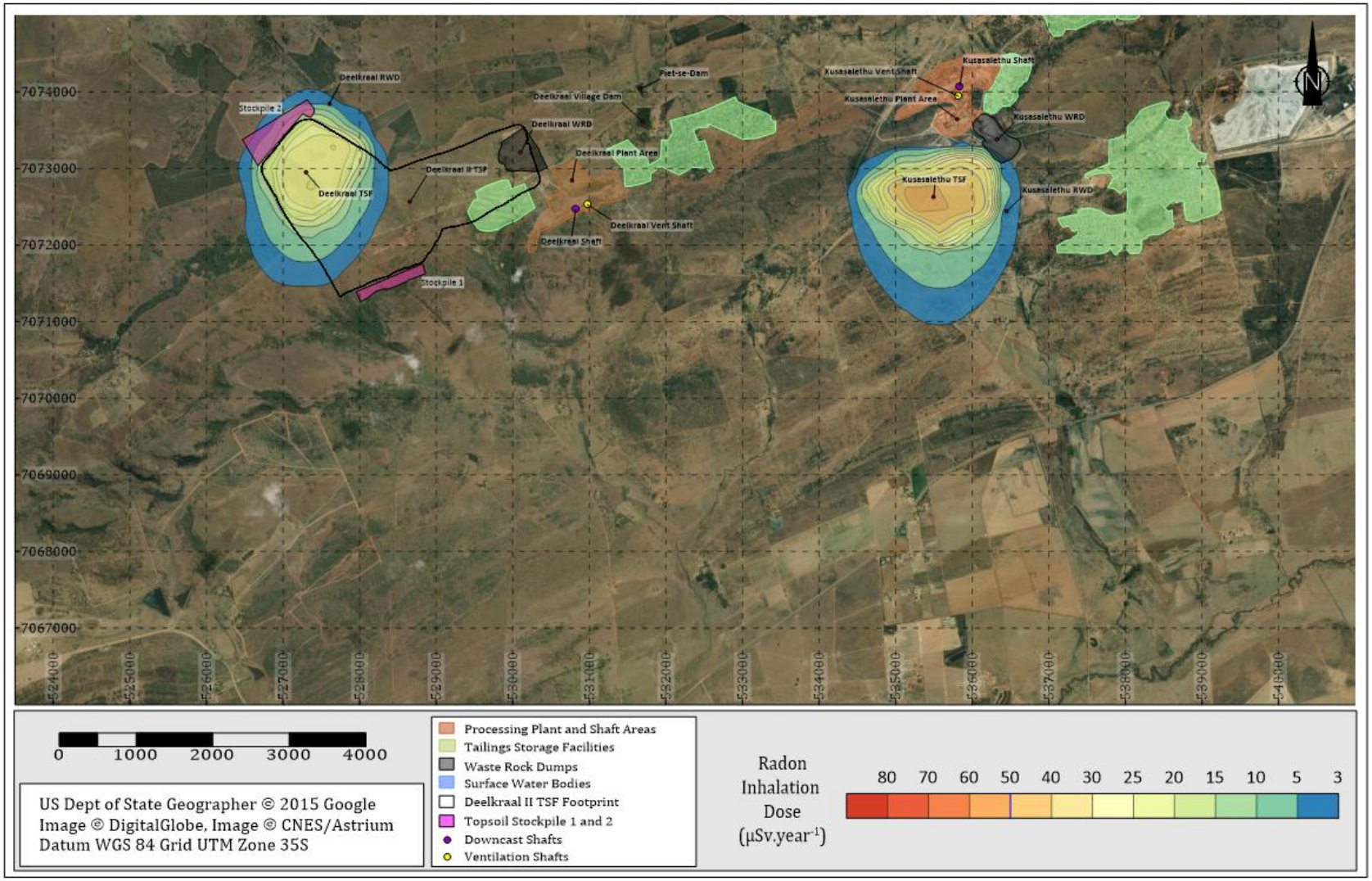


Figure 5.5 **The distribution of the adult radon inhalation dose induced by the current facilities associated with the Kusasalethu Operations, based on the airborne radon concentration presented in Figure 4.5.**

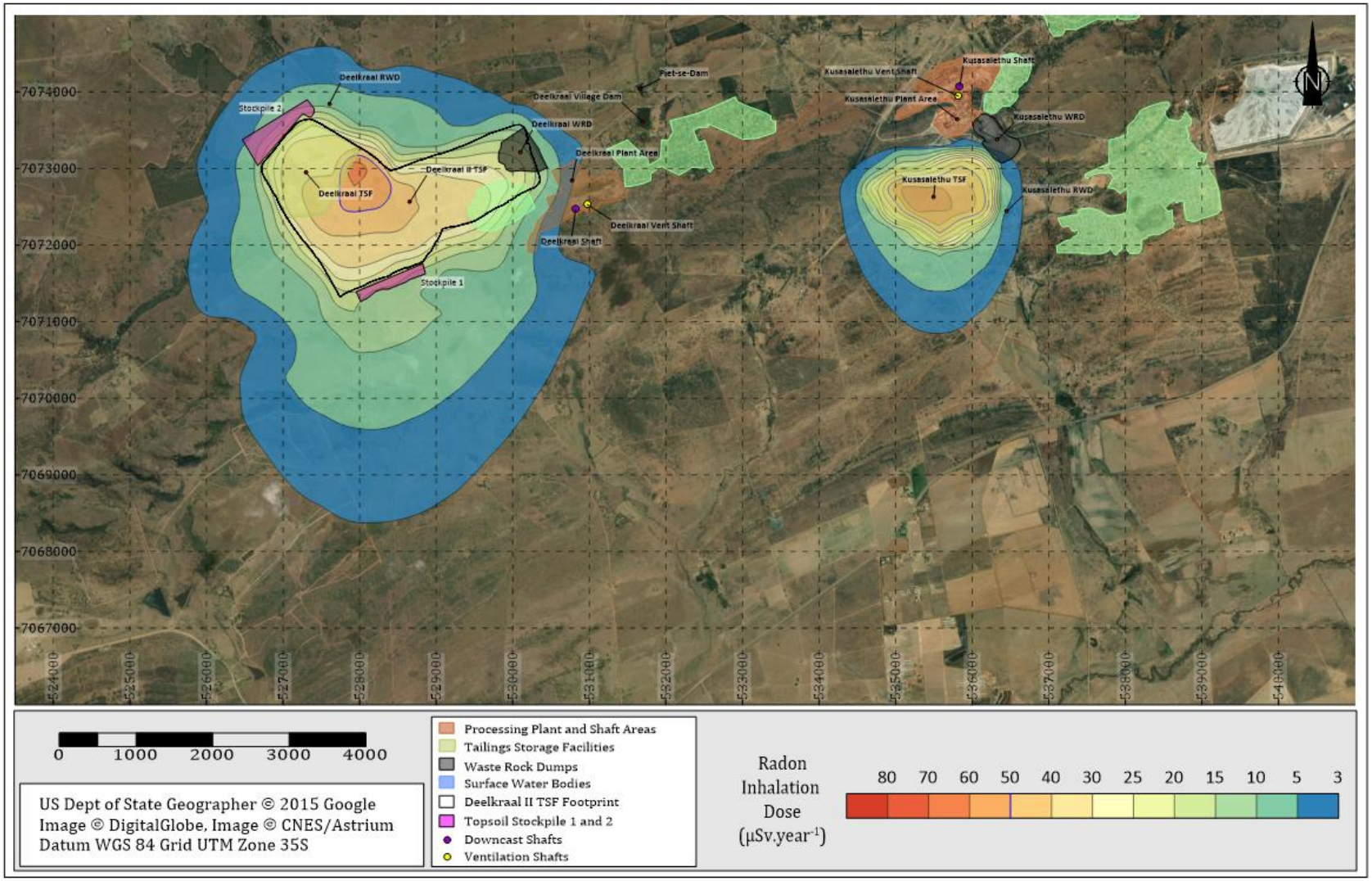


Figure 5.6 **The distribution of the adult radon inhalation dose induced by the future facilities associated with the Project, based on the airborne radon concentration presented in Figure 4.6.**

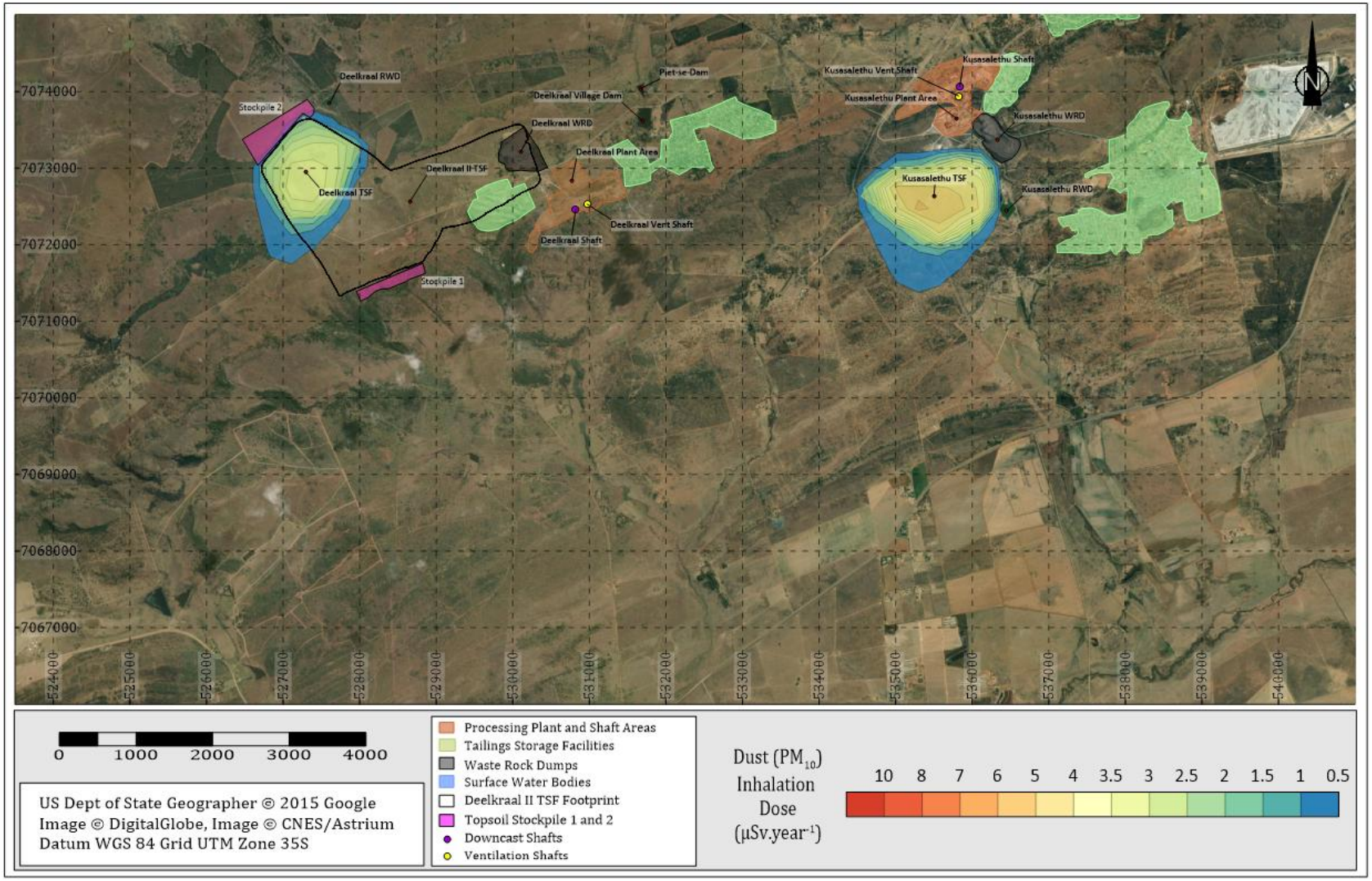


Figure 5.7 **The simulated current annual average adult airborne dust inhalation dose (in units of µSv.year^{-1}) as derived from PM_{10} data presented in Section 4.4.2.**

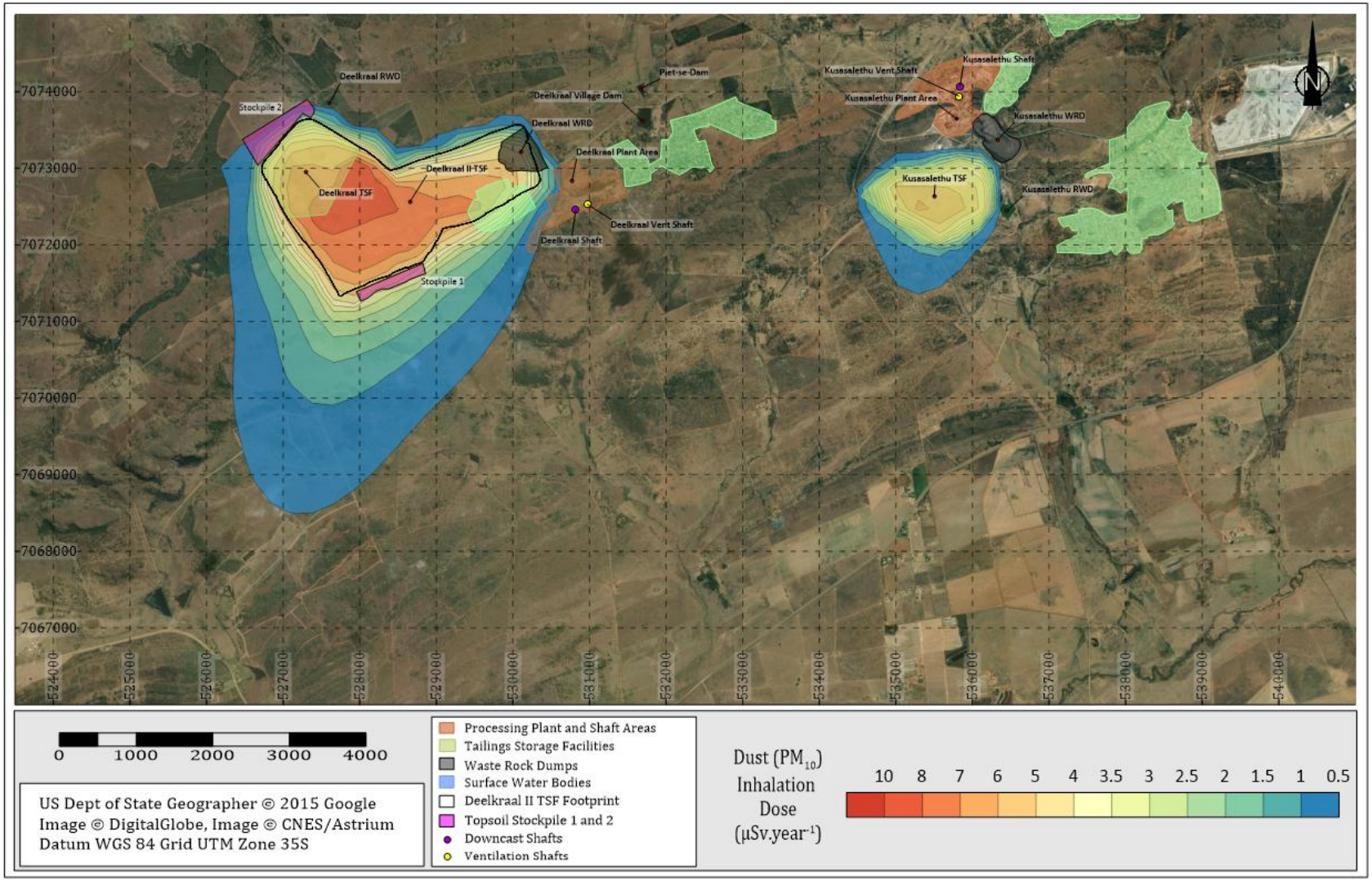


Figure 5.8 **The simulated future annual average adult airborne dust inhalation dose (in units of µSv.year^{-1}) as derived from PM_{10} data presented in Section 4.4.2.**

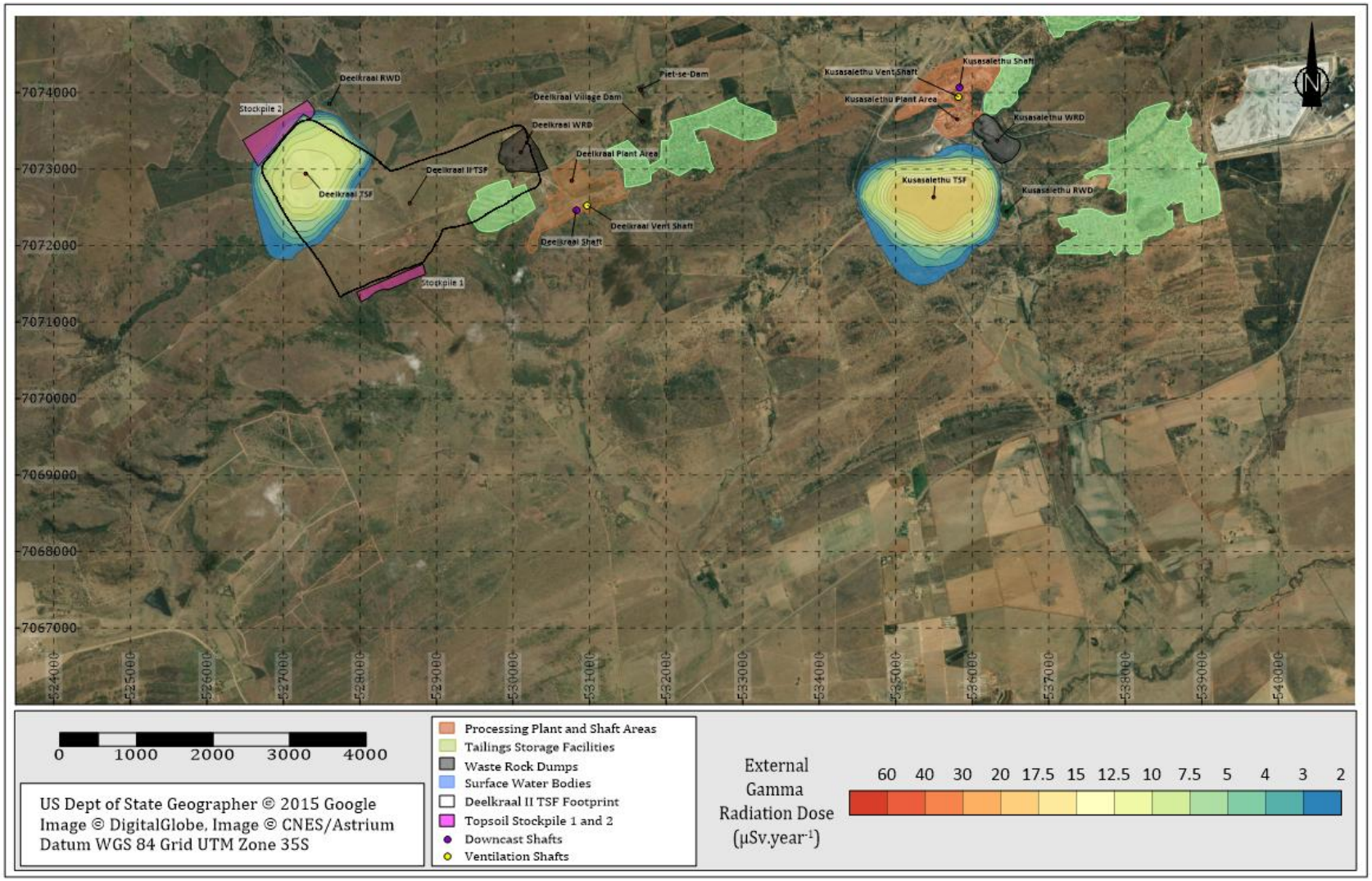


Figure 5.9 The current annual average adult external gamma radiation dose (in units of µSv.year^{-1}) as a contribution from groundshine, as derived from TSP data presented in Section 4.4.2

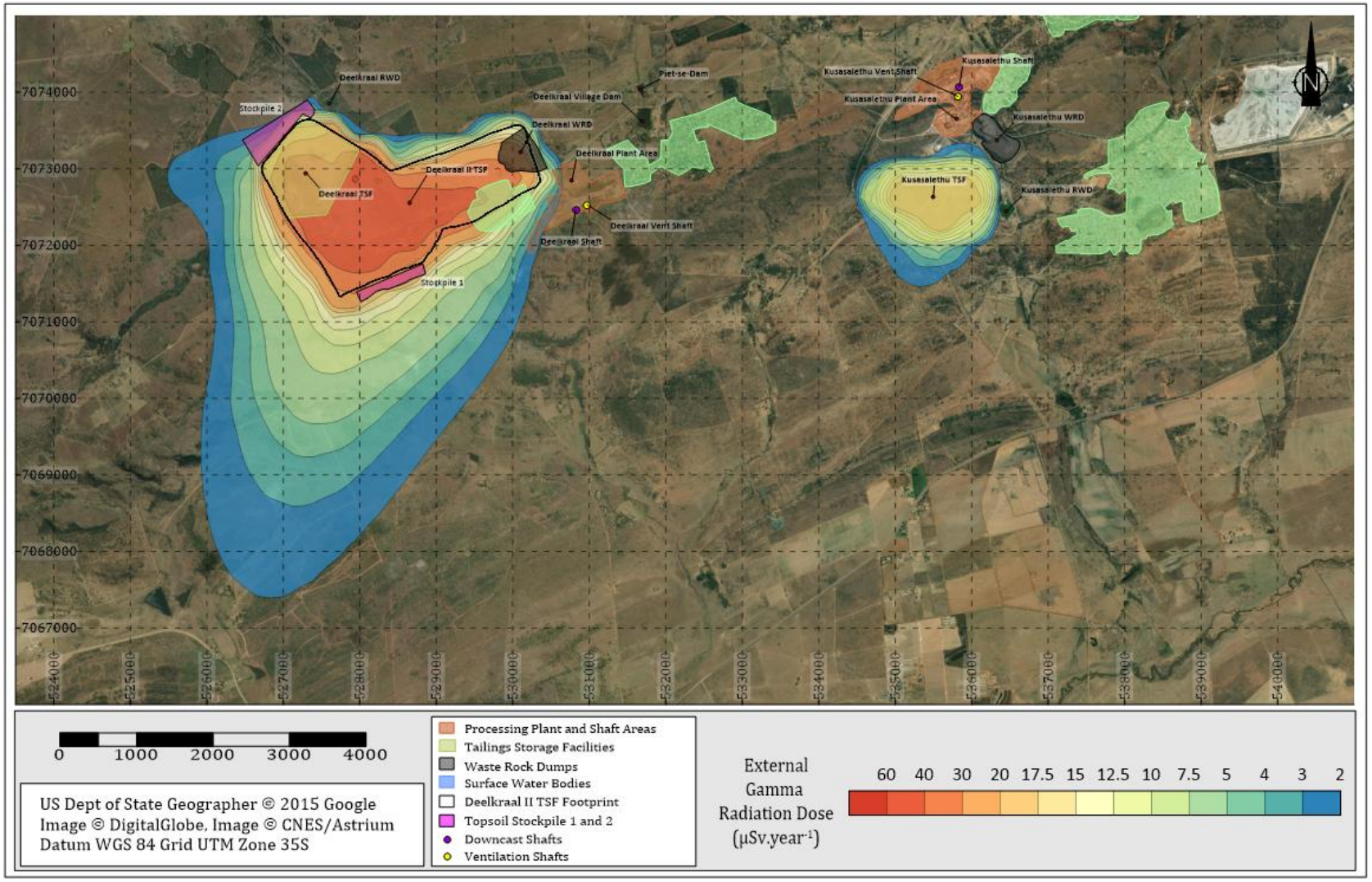


Figure 5.10 The future annual average adult external gamma radiation dose (in units of µSv.year^{-1}) as a contribution from groundshine, as derived from TSP data presented in Section 4.4.2

5.3.7 Dose Due to Deposition

The atmospheric pathway may also contribute to the total effective dose following deposition and the subsequent build-up of radioactivity in surface soil. This results in the transfer of radioactivity to plants and animal products, which introduces secondary pathways of concern. The contribution of deposition to the total effective dose is therefore a function of the deposition period and the exposure conditions defined for the assessment. The contribution of deposition to the total effective dose is discussed in more detail in Section 5.3.7.

5.4 Total Effective Dose Calculation for Exposure Conditions

5.4.1 General

The purpose of this section is to present the results of the total effective dose calculations for both the Residential Area Exposure Condition and Commercial Agricultural Exposure Condition defined for the Project in Section 4.8. Given the nature of the exposure conditions and the potential contributions of different environmental pathways to the total effective dose, the results presented here focus on the atmospheric pathway.

5.4.2 Mathematical Equations Used in the Biosphere Analysis

The mathematical equations and associated parameter values used in the biosphere analysis are documented in ARP Consulting (2026) (Section 4). They can be summarised as follows:

- **Equation 7 to Equation 11**: Calculate the radon concentration released from a stockpile facility, as well as the resulting airborne radon concentration.
- **Equation 12 to Equation 25**: Calculate the change in soil activity concentration with time due to the deposition of airborne contamination and the use of contaminated water for irrigation.
- **Equation 26**: Calculate the concentration in crops (e.g., vegetables, grains, or fruits).
- **Equation 27**: Calculate the concentration in the pasture, used to feed animals.
- **Equation 28 to Equation 29**: Calculate the concentration of animal products (e.g., meat, poultry, milk, eggs).
- **Equation 30 to Equation 35**: Calculate the effective dose to members of the public due to direct ingestion of contaminated water, soil, fish, crops, and animal products.
- **Equation 36 to Equation 38**: Calculate the effective dose for members of the public due to external exposure to radioactivity from contaminated water, contaminated air, and contaminated soil.
- **Equation 39 and Equation 40**: Effective dose to members of the public due to direct inhalation of contaminated (LLα) dust and radon.

5.4.3 Residential Area Exposure Condition

5.4.3.1 General

The purpose of the Residential Area Exposure Condition, as defined in Section 4.8.3, is to evaluate the radiological consequences to members of the public living in residential areas towards the east of the

Project. The main contributors to the total effective dose under the Residential Area Exposure Condition are atmospheric, surface water, and associated secondary pathways. Surface water is used to maintain a household garden, as a household water source, and to supply livestock. This means that the routes of exposure of concern include inhalation, ingestion, and external exposure. The expected exposures associated with each route include (see Section 4.8.3):

- Inhalation of radon n gas and dust containing LLα.
- Ingestion of contaminated produce (fruit, leafy and root vegetables) harvested from the household garden (50% annual consumption rate).
- Ingestion of contaminated animal products (meat and eggs) reared in the yard (50% annual consumption rate);
- Inadvertent ingestion of contaminated soil.
- Ingestion of contaminated surface water.
- External exposure to radionuclides deposited in the upper soil layer (ground shine) and external exposure to airborne LLα (cloud shine).
- External exposure to contaminated surface water (during bathing).

5.4.3.2 Dose Assessment

The conceptual model for the Residential Area Exposure Condition indicates that the main contributor to the total effective dose is atmospheric conditions and associated secondary pathways (i.e., ambient air). These pathways may include contributions from external gamma radiation, internal exposure following ingestion of contaminated soil, crops, and animal products, and internal exposure from inhalation of airborne radon and LLα dust. The exposure condition assumes that soil, crops, and animal products are ingested at 100%, 50% and 50% of the published annual ingestion rates, respectively. The exposure condition assumes a 75-year TSP deposition period. This assumption is conservative given the history of the mining activities in the area.

5.4.3.3 Results

Figure 5.11 presents the total effective dose isopleths for the 0 to 2 years age group, which receives the highest total effective dose of the 5 age categories. The approximate locations of the closest residential receptors are indicated on the maps with blue and white dots. Figure 5.11 shows that the distribution of the total effective dose across the affected areas is consistent with contributions from the atmospheric pathway (i.e., PM_{10}, TSP, and radon), with ingestion being the dominant contributor, followed by radon inhalation.

Figure 5.12 shows the total effective dose for different age groups at the 6 identified receptor locations (see Figure 5.11 for locations). Under regulatory practice, the evaluation of the annual effective dose focuses on the most-exposed population or critical group. According to Figure 5.12, the most affected residential receptor location is Res 5, located directly downstream of the Kusasalethu TSF. Exposure at this receptor is an order of magnitude higher than the other five receptors, peaking at approximately 52 $\mu Sv.year^{-1}$. To demonstrate the relative differences in exposure and provide context for the dose assessment results, route-specific dose results at the receptor locations are summarised in Table 5.7.

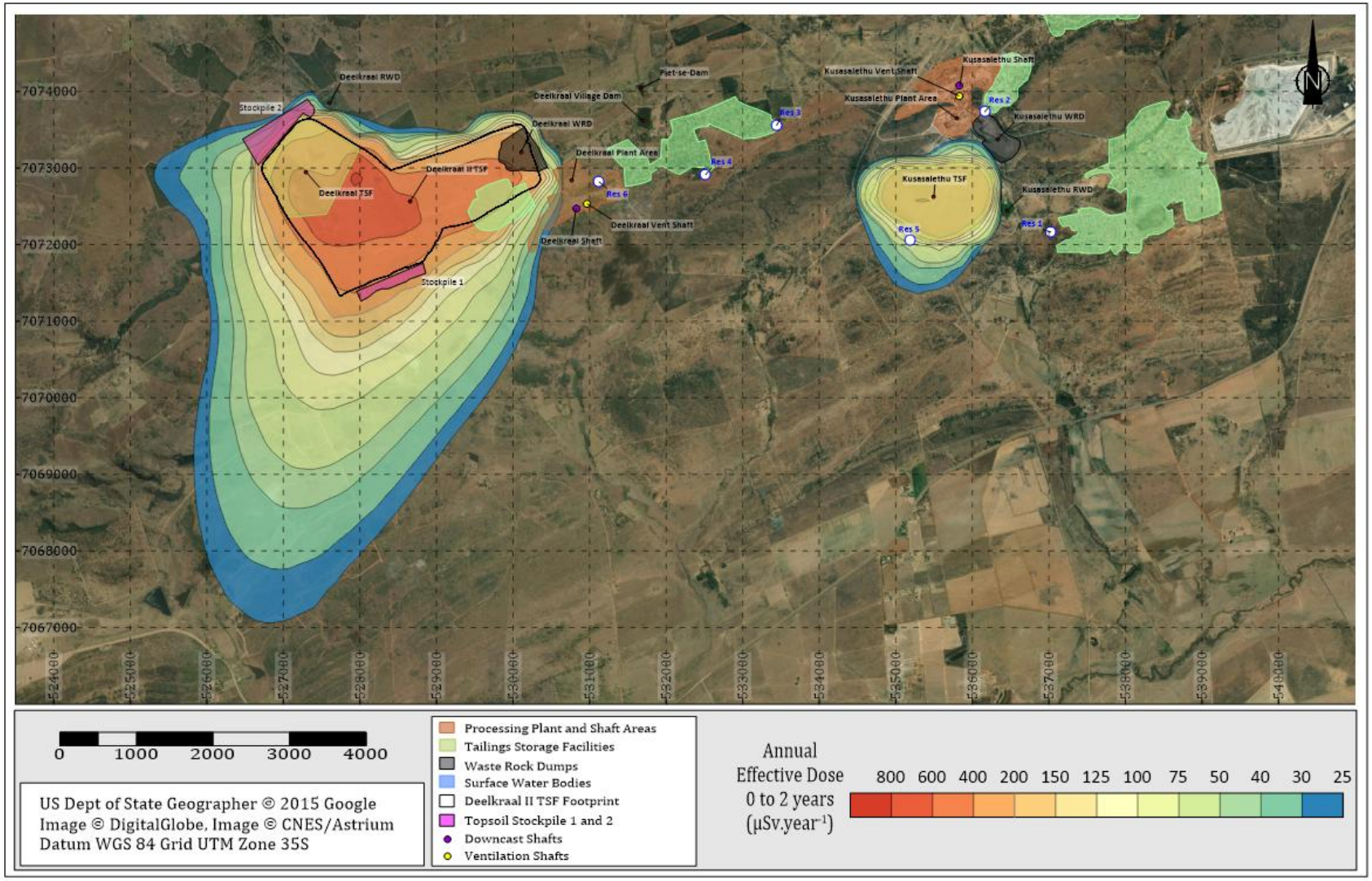


Figure 5.11 Dose isopleths for the 0 to 2 years age group depicting the contribution of the Project to a Residential Area Exposure Condition.

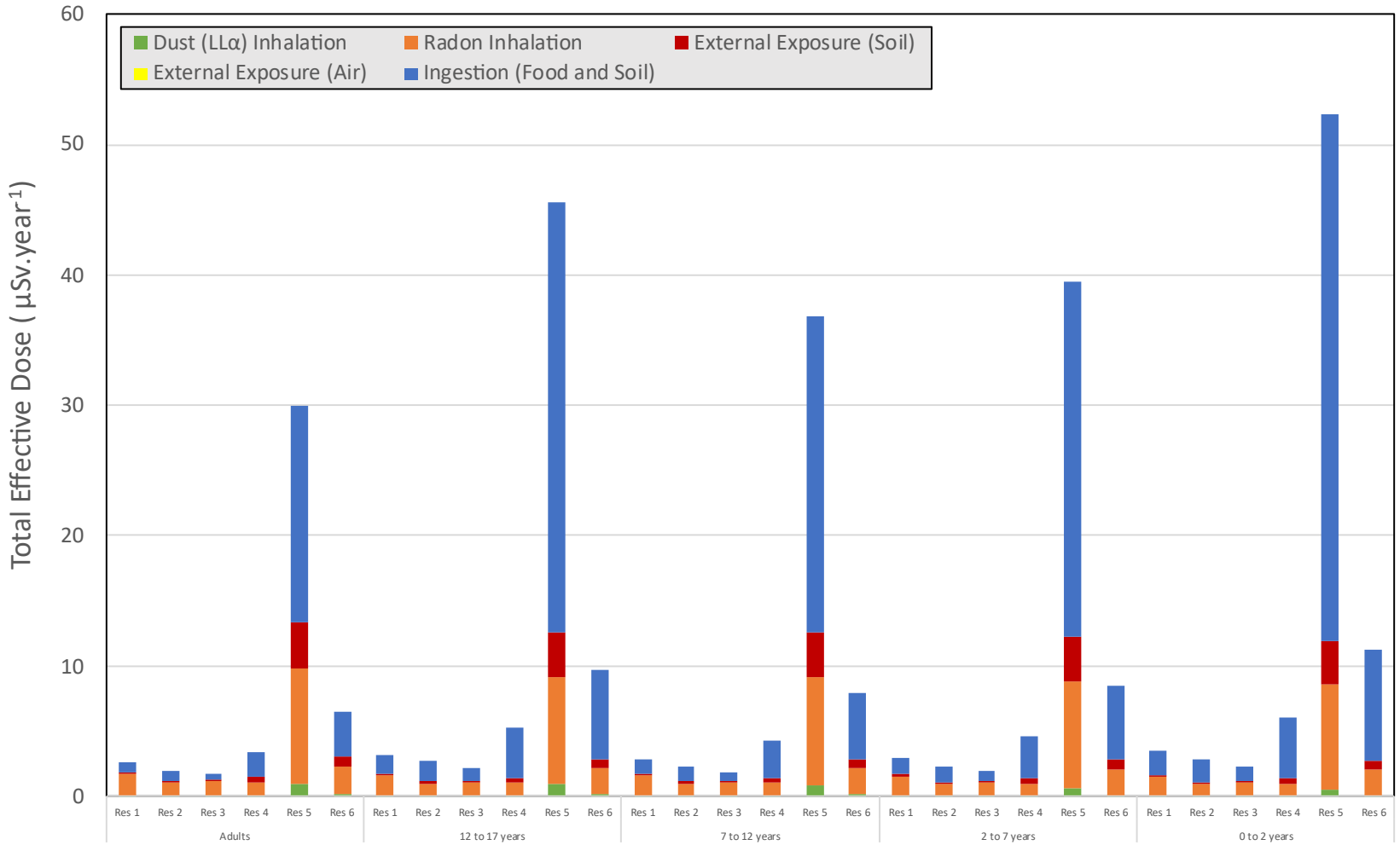


Figure 5.12 **Total effective doses to different age groups at receptor locations identified for the Residential Area Exposure Condition (see Figure 5.11 for locations).**

Table 5.7 Route-specific contribution to the total effective dose at receptor locations identified for the Residential Area Exposure Condition (see Figure 5.11).

Receptor Location	Age Groups	Dust (LLα)	Radon	External	External	Ingestion
		Inhalation	Inhalation	Exposure (Air)	Exposure (Soil)	Exposure (Food)
Res 1	Adults	5.42E-02	1.62E+00	1.59E-01	5.27E-08	7.28E-01
	12 to 17 Years	5.17E-02	1.52E+00	1.50E-01	4.96E-08	1.46E+00
	7 to 12 Years	4.51E-02	1.54E+00	1.51E-01	5.01E-08	1.07E+00
	2 to 7 Years	3.58E-02	1.51E+00	1.48E-01	4.91E-08	1.21E+00
	0 to 2 Years	3.18E-02	1.48E+00	1.46E-01	4.84E-08	1.79E+00
Res 2	Adults	5.09E-02	9.95E-01	1.64E-01	5.36E-08	7.14E-01
	12 to 17 Years	4.87E-02	9.36E-01	1.54E-01	5.04E-08	1.55E+00
	7 to 12 Years	4.24E-02	9.46E-01	1.56E-01	5.10E-08	1.10E+00
	2 to 7 Years	3.37E-02	9.26E-01	1.53E-01	4.99E-08	1.20E+00
	0 to 2 Years	2.98E-02	9.13E-01	1.50E-01	4.92E-08	1.77E+00
Res 3	Adults	2.43E-02	1.11E+00	1.03E-01	2.51E-08	4.79E-01
	12 to 17 Years	2.32E-02	1.04E+00	9.65E-02	2.36E-08	9.53E-01
	7 to 12 Years	2.03E-02	1.05E+00	9.75E-02	2.38E-08	7.05E-01
	2 to 7 Years	1.61E-02	1.03E+00	9.55E-02	2.33E-08	7.95E-01
	0 to 2 Years	1.43E-02	1.02E+00	9.41E-02	2.30E-08	1.18E+00
Res 4	Adults	1.08E-01	9.73E-01	4.19E-01	1.07E-07	1.94E+00
	12 to 17 Years	1.03E-01	9.16E-01	3.94E-01	1.00E-07	3.86E+00
	7 to 12 Years	8.97E-02	9.25E-01	3.99E-01	1.01E-07	2.84E+00
	2 to 7 Years	7.13E-02	9.06E-01	3.90E-01	9.91E-08	3.21E+00
	0 to 2 Years	6.34E-02	8.93E-01	3.85E-01	9.77E-08	4.75E+00
Res 5	Adults	9.47E-01	8.81E+00	3.62E+00	8.99E-07	1.65E+01
	12 to 17 Years	9.04E-01	8.29E+00	3.41E+00	8.46E-07	3.30E+01
	7 to 12 Years	7.88E-01	8.38E+00	3.44E+00	8.55E-07	2.42E+01
	2 to 7 Years	6.25E-01	8.20E+00	3.37E+00	8.37E-07	2.73E+01
	0 to 2 Years	5.56E-01	8.09E+00	3.32E+00	8.25E-07	4.04E+01
Res 6	Adults	1.78E-01	2.13E+00	7.34E-01	1.86E-07	3.45E+00
	12 to 17 Years	1.70E-01	2.01E+00	6.91E-01	1.75E-07	6.84E+00
	7 to 12 Years	1.49E-01	2.03E+00	6.98E-01	1.77E-07	5.06E+00
	2 to 7 Years	1.18E-01	1.99E+00	6.84E-01	1.73E-07	5.72E+00
	0 to 2 Years	1.05E-01	1.96E+00	6.74E-01	1.70E-07	8.49E+00

5.4.3.4 Interpretation of Results

As seen from the available results, dose concentrations decrease significantly with increasing distance from the associated facilities. A comparison of assessment results in Figure 5.12 and Table 5.7 shows that at the 6 residential receptor locations, ingestion followed by radon inhalation are the major contributors to the total effective dose. Contributions from all exposure routes are considered low to insignificant. In all cases, the total effective dose values remain well below the 250 μSv.year^{-1} dose constraint.

Note that, although there are no nearby residential receptors, the maximum total effective doses outside the footprint of the Deelkraal II TSF are as high as 450 μSv.year^{-1}, which is considerably higher than the dose constraint of 250 μSv.year^{-1}. This could be attributed to the high TSP deposition rates.

5.4.4 Commercial Agricultural Exposure Condition

5.4.4.1 General

The purpose of the Commercial Agricultural Exposure Condition is to evaluate the radiological consequences to members of the public practising farming near the Project. The exposure condition is defined conservatively to encompass any farming activity under the conditions and assumptions outlined in the definition of the Commercial Agricultural Exposure Condition (e.g., commercial agricultural, small-scale, or subsistence farming). It is conservatively assumed that the farmer, farm workers, and their families depend on the land for the annual consumption of cereals, fruits, and vegetables, as well as animal products such as eggs, milk, and meat.

The main contributors to a total effective dose are the atmospheric, groundwater and associated secondary pathways. Groundwater is used to sustain the farm system through irrigation and to supply livestock. In addition to the conditions and assumptions presented above, the following are assumed for the Commercial Agricultural Exposure Condition:

- Inhalation of radon and thoron gas and dust containing LLα.
- Ingestion of contaminated produce (grain/maize, fruit, leafy and root vegetables) harvested from the subsistence farm (100% annual consumption rate).
- Ingestion of contaminated animal products (meat, milk and eggs) reared on the farm (100% annual consumption rate).
- Inadvertent ingestion of contaminated soil.
- Ingestion of contaminated groundwater.
- External exposure to radionuclides deposited in the upper soil layer (ground shine) and external exposure to airborne LLα (cloud shine).
- External exposure to contaminated groundwater (during bathing).

A 75-year dust deposition period is assumed to estimate radionuclide buildup in the topsoil layer, which is very conservative.

Note that the definition of the Commercial Agricultural Exposure Condition assumed a contribution of the aquatic pathway to the total effective dose, mainly through the groundwater pathway or the surface water pathway as an extension of the groundwater pathway. However, Section 5.2 illustrated that the potential contribution of the groundwater pathway is only possible over about 10,000 years at doses below 200 $\mu Sv.year^{-1}$. The timescales of concern for the atmospheric and aquatic pathways differ, and they cannot be combined to calculate the total effective dose.

5.4.4.2 Dose Assessment

The conceptual model for the Commercial Agricultural Exposure Condition indicates that the main contributors to the total effective dose are atmospheric (i.e., ambient air conditions), aquatic, and associated secondary pathways. These pathways may include contributions from external gamma radiation from groundshine, cloudshine, and water immersion; internal exposure following ingestion of contaminated water, soil, crops, and animal products; and internal exposure from the inhalation of airborne radon and LLα dust. The exposure condition assumes that soil, crops and animal products are ingested at 100% of the annual ingestion rates presented in RG-002 (NNR, 2013). The exposure condition

assumes a 75-year TSP and water deposition period, which is conservative given the history of the Kusasalethu Operations.

Similarly, uncertainties regarding the contaminated surface water released from the Project into downstream surface water features make it difficult to quantify potential radiological impacts from the operations via the surface-water pathway. Both the groundwater pathway and surface water pathway are thus excluded from the evaluation of the Commercial Agricultural Exposure Condition. The potential contribution of the aquatic pathway will therefore be further evaluated as part of the sensitivity analysis (see Section 6.2).

5.4.4.3 Results

Figure 5.13 presents the total effective dose isopleths for the 0 to 2 years age group, which receives the highest total effective dose of the 5 categories. The approximate locations of the closest agricultural receptors are indicated on the maps with green and white dots. Figure 5.13 shows that the distribution of the total effective dose across the affected areas is consistent with contributions from the atmospheric pathway (i.e., PM_{10}, TSP, and radon), with ingestion being the dominant contributor.

Figure 5.14 shows the total effective dose for different age groups at the 11 identified receptor locations (see Figure 5.13 for locations). Under regulatory practice, the evaluation of the annual effective dose focuses on the most-exposed population or critical group.

According to Figure 5.14, the most affected agricultural receptor locations are Farm 7 and Farm 8, which were conceptually placed directly adjacent to the Deelkraal II TSF. Upon inspection of the Social Impact Assessment receptors and consultation of Google imagery, no farming accommodation structures are located within the impact zone directly south of the proposed Deelkraal II TSF. However, cropland and irrigation infrastructure are evident and therefore warrant evaluation of agricultural practices.

Exposure at these receptors is an order of magnitude higher than the other 9 receptors, peaking at approximately 280 $\mu Sv.year^{-1}$. To demonstrate the differences in exposure and provide context for the dose assessment results, route-specific dose results at the receptor locations are summarised in Table 5.8.

5.4.4.4 Interpretation of Results

As seen from the available results, dose concentrations decrease significantly with increasing distance from the associated facilities. A comparison of assessment results in Figure 5.14 and Table 5.8 shows that at the 11 receptor locations, ingestion is the major contributor to the total effective dose, followed by external exposure. This could be attributed directly to the high TSP deposition rate associated with the Deelkraal II TSF. In fact, the maximum total effective doses outside the footprint of the Deelkraal II TSF are as high as 850 $\mu Sv.year^{-1}$, which is considerably higher than the dose constraint of 250 $\mu Sv.year^{-1}$. The contributions from all remaining routes are considered low to insignificant.

At specific receptor locations, 10 of the 11 cases result in total effective dose values well below the 250 $\mu Sv.year^{-1}$ dose constraint. The exception is the Farm 7 receptor location, which could receive total doses of up to 280 $\mu Sv.year^{-1}$, slightly above the dose constraint. Note that this applies only to the 0 to 2 year age group, with all other age groups having effective doses below 250 $\mu Sv.year^{-1}$.

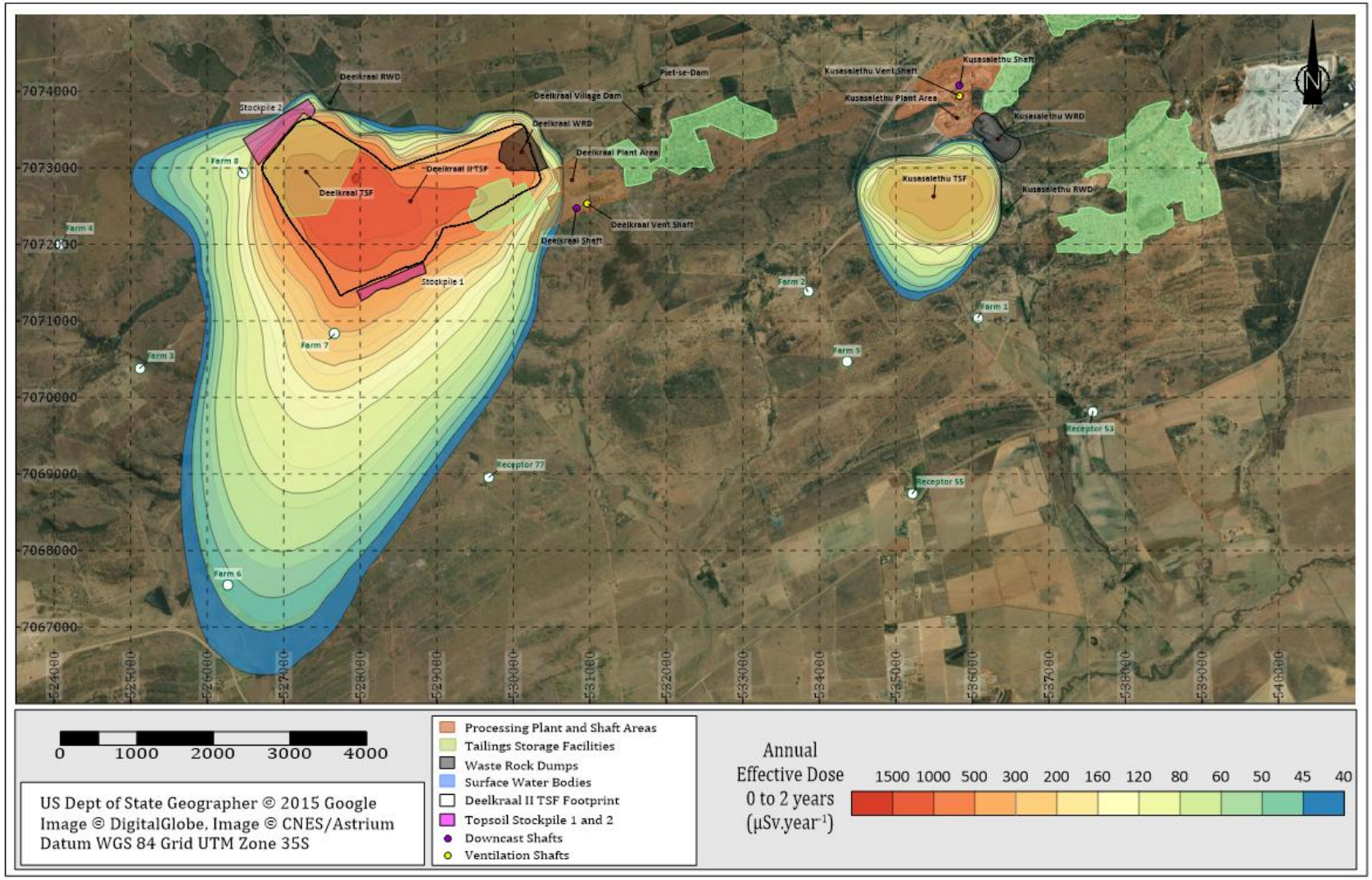


Figure 5.13 Dose isopleths for the adult age group depicting the contribution of the Project to a Commercial Agricultural Exposure Condition.

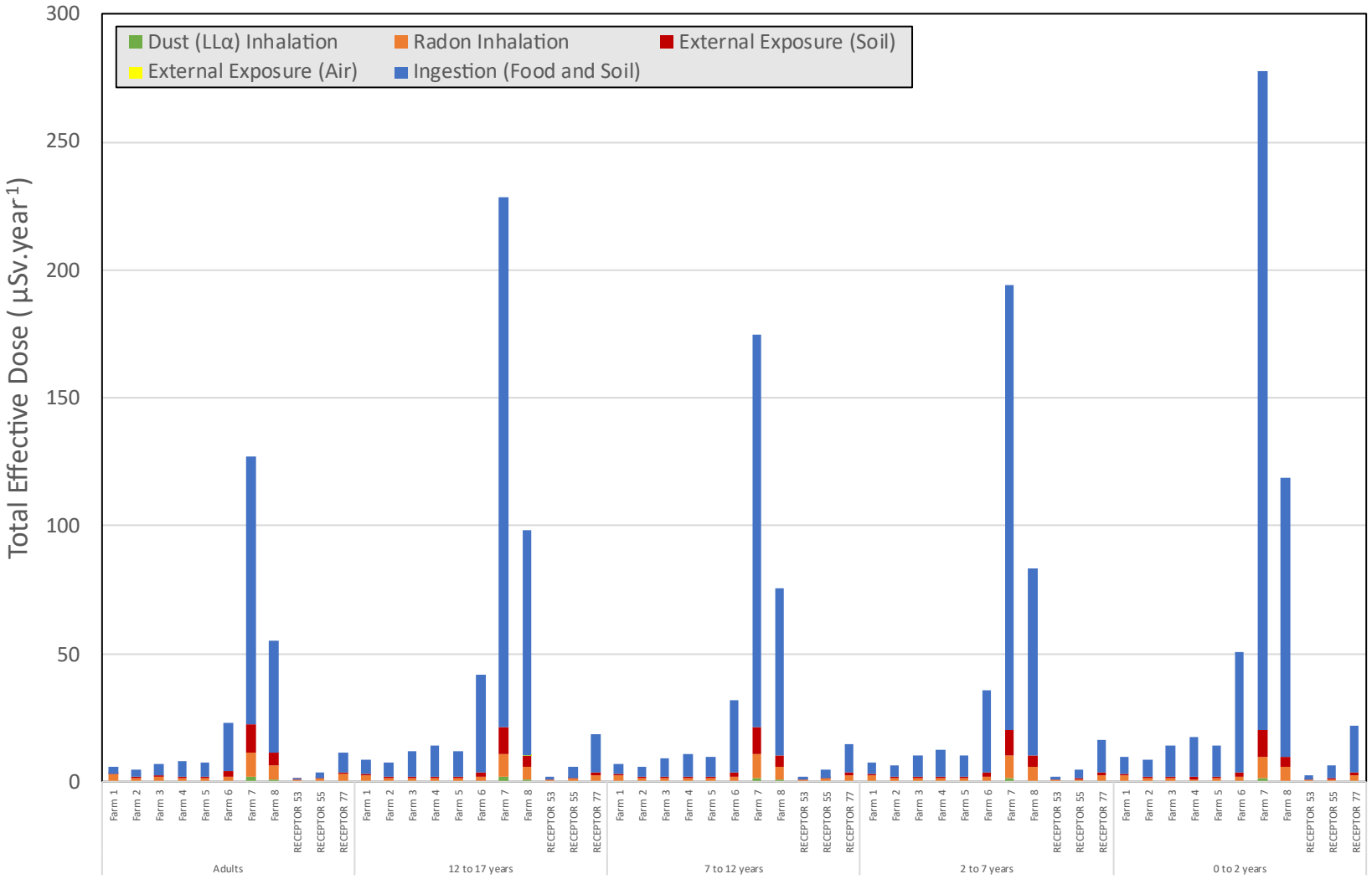


Figure 5.14 **Total effective doses to different age groups at receptor locations identified for the Commercial Agricultural Exposure Condition (see Figure 5.13 for locations).**

Table 5.8 Route-specific contribution to the total effective dose at receptor locations identified for the Commercial Agricultural Exposure Condition (see Figure 5.13).

Receptor Location	Age Groups	Dust (LLα)	Radon	External	External	Ingestion
		Inhalation	Inhalation	Exposure (Air)	Exposure (Soil)	Exposure (Food)
Farm 1	Adults	9.53E-02	2.76E+00	3.09E-01	9.20E-08	2.80E+00
	12 to 17 Years	9.09E-02	2.60E+00	2.90E-01	8.66E-08	5.62E+00
	7 to 12 Years	7.92E-02	2.62E+00	2.93E-01	8.75E-08	4.13E+00
	2 to 7 Years	6.29E-02	2.57E+00	2.87E-01	8.56E-08	4.64E+00
	0 to 2 Years	5.59E-02	2.53E+00	2.83E-01	8.44E-08	6.87E+00
Farm 2	Adults	6.55E-02	1.53E+00	3.07E-01	6.50E-08	2.82E+00
	12 to 17 Years	6.25E-02	1.44E+00	2.89E-01	6.11E-08	5.62E+00
	7 to 12 Years	5.45E-02	1.45E+00	2.92E-01	6.18E-08	4.15E+00
	2 to 7 Years	4.34E-02	1.42E+00	2.86E-01	6.05E-08	4.67E+00
	0 to 2 Years	3.85E-02	1.40E+00	2.82E-01	5.96E-08	6.93E+00
Farm 3	Adults	7.24E-02	1.70E+00	5.18E-01	7.71E-08	4.86E+00
	12 to 17 Years	6.92E-02	1.60E+00	4.87E-01	7.25E-08	9.63E+00
	7 to 12 Years	6.03E-02	1.62E+00	4.92E-01	7.32E-08	7.14E+00
	2 to 7 Years	4.81E-02	1.58E+00	4.82E-01	7.17E-08	8.07E+00
	0 to 2 Years	4.28E-02	1.56E+00	4.75E-01	7.07E-08	1.20E+01
Farm 4	Adults	1.03E-01	1.17E+00	6.71E-01	1.09E-07	6.30E+00
	12 to 17 Years	9.85E-02	1.10E+00	6.31E-01	1.03E-07	1.25E+01
	7 to 12 Years	8.59E-02	1.11E+00	6.38E-01	1.04E-07	9.25E+00
	2 to 7 Years	6.85E-02	1.09E+00	6.25E-01	1.02E-07	1.05E+01
	0 to 2 Years	6.09E-02	1.08E+00	6.16E-01	1.00E-07	1.55E+01
Farm 5	Adults	1.51E-01	1.52E+00	5.51E-01	1.46E-07	5.03E+00
	12 to 17 Years	1.45E-01	1.43E+00	5.19E-01	1.37E-07	1.00E+01
	7 to 12 Years	1.26E-01	1.44E+00	5.24E-01	1.39E-07	7.38E+00
	2 to 7 Years	1.00E-01	1.41E+00	5.13E-01	1.36E-07	8.31E+00
	0 to 2 Years	8.89E-02	1.39E+00	5.06E-01	1.34E-07	1.23E+01
Farm 6	Adults	3.36E-01	1.67E+00	2.04E+00	3.59E-07	1.92E+01
	12 to 17 Years	3.21E-01	1.57E+00	1.92E+00	3.37E-07	3.80E+01
	7 to 12 Years	2.80E-01	1.59E+00	1.94E+00	3.41E-07	2.82E+01
	2 to 7 Years	2.23E-01	1.55E+00	1.90E+00	3.34E-07	3.19E+01
	0 to 2 Years	1.99E-01	1.53E+00	1.88E+00	3.29E-07	4.73E+01
Farm 7	Adults	2.03E+00	9.35E+00	1.11E+01	2.17E-06	1.05E+02
	12 to 17 Years	1.94E+00	8.80E+00	1.05E+01	2.04E-06	2.07E+02
	7 to 12 Years	1.69E+00	8.89E+00	1.06E+01	2.06E-06	1.54E+02
	2 to 7 Years	1.35E+00	8.71E+00	1.04E+01	2.02E-06	1.74E+02
	0 to 2 Years	1.20E+00	8.58E+00	1.02E+01	1.99E-06	2.58E+02
Farm 8	Adults	7.29E-01	5.72E+00	4.71E+00	7.78E-07	4.41E+01
	12 to 17 Years	6.96E-01	5.38E+00	4.43E+00	7.32E-07	8.77E+01
	7 to 12 Years	6.07E-01	5.44E+00	4.48E+00	7.40E-07	6.49E+01
	2 to 7 Years	4.84E-01	5.32E+00	4.38E+00	7.24E-07	7.33E+01
	0 to 2 Years	4.31E-01	5.25E+00	4.32E+00	7.14E-07	1.09E+02
RECEPTOR 53	Adults	2.21E-02	7.68E-01	7.50E-02	2.20E-08	6.89E-01
	12 to 17 Years	2.11E-02	7.22E-01	7.06E-02	2.07E-08	1.38E+00
	7 to 12 Years	1.84E-02	7.30E-01	7.13E-02	2.09E-08	1.02E+00
	2 to 7 Years	1.46E-02	7.14E-01	6.98E-02	2.05E-08	1.14E+00
	0 to 2 Years	1.30E-02	7.04E-01	6.88E-02	2.02E-08	1.70E+00
RECEPTOR 55	Adults	7.17E-02	1.16E+00	2.32E-01	6.99E-08	2.12E+00
	12 to 17 Years	6.85E-02	1.09E+00	2.18E-01	6.57E-08	4.24E+00
	7 to 12 Years	5.97E-02	1.10E+00	2.21E-01	6.64E-08	3.12E+00
	2 to 7 Years	4.74E-02	1.08E+00	2.16E-01	6.50E-08	3.52E+00
	0 to 2 Years	4.21E-02	1.07E+00	2.13E-01	6.41E-08	5.21E+00
RECEPTOR 77	Adults	1.61E-01	2.78E+00	8.12E-01	1.72E-07	7.62E+00
	12 to 17 Years	1.54E-01	2.61E+00	7.64E-01	1.62E-07	1.51E+01
	7 to 12 Years	1.34E-01	2.64E+00	7.72E-01	1.63E-07	1.12E+01
	2 to 7 Years	1.07E-01	2.58E+00	7.56E-01	1.60E-07	1.27E+01
	0 to 2 Years	9.54E-02	2.55E+00	7.45E-01	1.58E-07	1.88E+01

6 Sensitivity and Uncertainty Analysis

6.1 General

The consequence analysis presented in Section 5 is based on several conditions and parameter values that were presented in the *System Description (see Section 3)*, the *Definition and Justification of Public Exposure Conditions* (see Section 4) and the *Mathematical Model Development* (AquiSim, 2024). These results are viewed as the most realistic and representative of the potential radiological impact on members of the public residing near the Project. However, the nature of a safety assessment for a mining and mineral processing operation means that uncertainties exist in both the assumed conditions and the parameter values used. From this perspective, the inexact nature of safety assessments was highlighted in the *Assessment Context*.

The purpose of this section is to address some of these uncertainties and to evaluate the sensitivity of the assessment results to variations in conditions and parameter values. Viewed from this perspective, it serves as a "what if" analysis in support of the overall safety case for the Project.

The section is structured as follows. Section 6.2 further evaluates the potential contribution of the aquatic pathway to a total effective dose using the available public radiation protection programme monitoring results for the Project area. Section 6.3 then discusses the cumulative effect of other facilities and operations in the area, while Section 6.4 discusses the effect of variations in the public exposure conditions defined for the Project. In Section 6.5, the variation in parameter values is discussed.

6.2 Aquatic Pathway Analysis

6.2.1 General

The consequence analysis presented in Section 5 focused on the contribution of the atmospheric pathway to the total annual effective dose for each public exposure condition. Evaluation of the dose contribution from the aquatic pathways was excluded from this consequence analysis, based on results from the *System Level* modelling of the groundwater pathway, which indicated that radionuclides leached from the aquatic pathway source (e.g., tailings storage facilities or water management facilities) have limited mobility and are expected to remain below and near the source areas for extended periods. The likelihood of public exposure through the aquatic pathway is, therefore, similarly limited. However, the question remains whether radionuclides entering the aquatic pathways may lead to public radiation exposure.

The purpose of this section is to evaluate the potential for public exposure *via* aquatic pathways, using actual surface-water and groundwater monitoring results from selected locations. Harmony maintains surface water and groundwater monitoring programmes surrounding the Project to monitor levels and any possible changes in radionuclide concentrations in surface water and groundwater bodies. The results of this monitoring programme were summarised in Section 3.8. These results can be used to assess the potential impact of the Project on members of the public through the aquatic pathway. *However, it must be done with care since it is not necessarily clear what is naturally induced (i.e., background) and what is human-induced (i.e., a contribution from the mining operations).*

The approach followed for this purpose is to use the analysis results of surface water and groundwater monitoring on a conservative "what if" basis. In other words: "*What would the radiological consequences be if the observed surface water or groundwater monitoring results are used by members of the public practising subsistence agriculture activities near the Kusasalethu Operations?"*

6.2.2 Surface Water Pathway

6.2.2.1 General

The Kusasalethu Operations have been operational for some time, so a significant record of surface water monitoring data is available. Figure 3.53 shows the approximate locations of the surface water monitoring points surrounding the Project, while Table 6.1 summarises the radioanalysis results of routine surface water sampling points available for the Project area as reported in detail in Section 3.8. It consists of 3 sampling points at the Golf Course, the Deelkraal Village Dam and the Wedela Stream.

6.2.2.2 Dose Assessment

The data presented in Table 6.1 is used to assess the potential radiological dose to members of the public that utilise surface water for household and subsistence agricultural practices. However, as indicated earlier, this is a conservative "what if" evaluation and must be done with care.

The dose assessment is performed for the conditions consistent with a Subsistence Agricultural Exposure Condition. This public exposure condition is the most conservative and, therefore, also covers the conditions defined for smaller-scale residential food cultivation activities. For the Subsistence Agricultural Exposure Condition, it is assumed that the farmer and his family consume water, fish, soil, fruit, cereal, poultry milk, eggs, meat (mutton and beef), as well as leafy and root vegetables at 100% of the annual ingestion rates presented in RG-002 (NNR, 2013).

Furthermore, it is assumed that the water source is sufficient to sustain a farm system annually. The contribution from external gamma radiation is through water immersion (e.g., bathing and swimming) and groundshine following deposition. A 75-year irrigation period was assumed for the analysis.

Table 6.1 Summary of the surface water activity concentrations that are considered in the uncertainty analysis, as derived from the data presented in AquiSim (2023).

Radionuclide	Surface Water Sampling Point		
	Golf Course	Deelkraal Dam	Wedela Stream
	$mBq.L^{-1}$		
U-238	278.6	732.9	25.8
U-234	278.8	695.4	47.2
Th-230	77.9	68.3	42.0
Ra-226	43.9	15.2	7.2
Pb-210	47.8	12.7	20.8
Po-210	5.7	7.1	19.3
U-235	12.8	33.8	1.2
Th-227	11.7	8.7	8.2
Ra-223	7.8	5.6	4.3
Th-232	7.6	6.5	6.8
Th-228	8.9	9.2	10.0
Ra-224	6.4	9.3	5.7

6.2.2.3 Results

Table 6.2 to Table 6.4 present the estimated total effective dose values for the surface water monitoring data listed in Table 6.1, while Figure 6.1 summarises the total effective doses calculated across the different age groups at each point. The results presented in Table 6.2 to Table 6.4 and Figure 6.2 indicate that, in general, the contribution from external exposure is insignificant compared to that from ingestion of water, crops, and animal products. As expected, direct water ingestion is the most significant exposure route (between 50 and 65% of the total effective dose), followed by fish ingestion (between 19 and 35%). Note that the results presented here include the contribution from natural background radiation.

Table 6.2 Total effective dose induced using water for the Golf Course monitoring point for household and subsistence farming purposes.

Ingestion Dose in µSv.year^{1}					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	8.07E-01	5.72E-01	5.73E-01	9.06E-01	3.69E-01
Meat (Poultry)	1.58E+00	1.07E+00	8.57E-01	9.24E-01	7.69E-01
Meat (Mutton)	1.36E+00	1.08E+00	1.11E+00	1.66E+00	9.72E-01
Eggs	6.32E-01	4.32E-01	3.49E-01	3.81E-01	3.16E-01
Cereal (Grain)	3.08E+00	2.43E+00	2.54E+00	3.93E+00	2.03E+00
Root Vegetables	4.53E+00	3.50E+00	4.33E+00	8.47E+00	2.43E+00
Leafy Vegetables	5.17E+00	3.98E+00	4.56E+00	7.95E+00	2.75E+00
Fruits	3.32E+00	2.60E+00	2.89E+00	4.83E+00	1.98E+00
Soil (Cropland)	2.07E-01	1.63E-01	1.70E-01	2.64E-01	1.33E-01
Soil (Garden)	2.06E-01	1.63E-01	1.70E-01	2.63E-01	1.33E-01
Soil (Pasture)	2.06E-01	1.63E-01	1.70E-01	2.63E-01	1.33E-01
Milk	1.11E+00	8.79E-01	9.26E-01	1.42E+00	8.04E-01
Water	8.98E+01	7.09E+01	7.38E+01	1.14E+02	5.78E+01
Freshwater Fish	4.16E+01	3.14E+01	3.00E+01	4.04E+01	2.20E+01
Total Ingestion Dose	1.54E+02	1.19E+02	1.22E+02	1.86E+02	9.26E+01
Total External Dose	1.30E+00	1.52E+00	1.84E+00	1.68E+00	2.63E+00
Total Effective Dose	1.55E+02	1.21E+02	1.24E+02	1.88E+02	9.53E+01

Table 6.3 Total effective dose induced using water for the Deelkraal Village Dam monitoring point for household and subsistence farming purposes.

Ingestion Dose in µSv.year^{1}					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	7.92E-01	5.52E-01	4.98E-01	6.69E-01	3.69E-01
Meat (Poultry)	2.51E+00	1.78E+00	1.51E+00	1.76E+00	1.44E+00
Meat (Mutton)	2.14E+00	1.74E+00	1.73E+00	2.42E+00	1.77E+00
Eggs	1.03E+00	7.35E-01	6.31E-01	7.45E-01	6.08E-01
Cereal (Grain)	3.89E+00	3.17E+00	3.09E+00	4.26E+00	3.03E+00
Root Vegetables	3.47E+00	2.71E+00	3.10E+00	5.39E+00	2.07E+00
Leafy Vegetables	3.42E+00	2.69E+00	2.93E+00	4.74E+00	2.15E+00
Fruits	3.21E+00	2.58E+00	2.67E+00	4.01E+00	2.37E+00
Soil (Cropland)	2.43E-01	1.98E-01	1.92E-01	2.63E-01	1.85E-01
Soil (Garden)	2.43E-01	1.98E-01	1.91E-01	2.63E-01	1.85E-01
Soil (Pasture)	2.43E-01	1.98E-01	1.91E-01	2.63E-01	1.85E-01
Milk	2.00E+00	1.62E+00	1.62E+00	2.25E+00	1.65E+00
Water	1.05E+02	8.58E+01	8.30E+01	1.14E+02	8.03E+01
Freshwater Fish	4.02E+01	3.11E+01	2.72E+01	3.25E+01	2.49E+01
Total Ingestion Dose	1.69E+02	1.35E+02	1.29E+02	1.73E+02	1.21E+02
Total External Dose	8.60E-01	1.00E+00	1.21E+00	1.11E+00	1.74E+00
Total Effective Dose	1.70E+02	1.36E+02	1.30E+02	1.75E+02	1.23E+02

The highest contribution comes from the Golf Course for the 12 to 17 age group, but overall, Deelkraal Village points result in the highest doses across all age groups. However, all results are below 200 µSv.year^{-1}, indicating a relatively low contribution from surface water bodies to the total effective dose. Using the analysis results in Table 6.1 to calculate the total effective dose for a Subsistence Agricultural Exposure Condition therefore confirms that the potential contribution of surface water as a water source is relatively low compared with the dose limit or dose constraint, especially given the very conservative nature of the exposure condition.

Table 6.4 Total effective dose induced using water for the Wedela monitoring point for household and subsistence farming purposes.

Ingestion Dose in µSv.year^{1}					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	1.44E+00	9.28E-01	7.33E-01	8.02E-01	5.12E-01
Meat (Poultry)	3.94E+00	2.47E+00	1.77E+00	1.56E+00	1.37E+00
Meat (Mutton)	6.35E-01	4.58E-01	4.32E-01	5.86E-01	3.21E-01
Eggs	1.53E+00	9.60E-01	6.86E-01	6.09E-01	5.34E-01
Cereal (Grain)	1.91E+00	1.35E+00	1.26E+00	1.72E+00	8.87E-01
Root Vegetables	2.69E+00	1.95E+00	2.23E+00	3.84E+00	1.08E+00
Leafy Vegetables	2.74E+00	2.02E+00	2.20E+00	3.52E+00	1.18E+00
Fruits	1.60E+00	1.18E+00	1.27E+00	1.99E+00	7.39E-01
Soil (Cropland)	1.38E-01	9.71E-02	9.02E-02	1.22E-01	6.33E-02
Soil (Garden)	1.37E-01	9.67E-02	8.98E-02	1.21E-01	6.30E-02
Soil (Pasture)	1.37E-01	9.67E-02	8.98E-02	1.21E-01	6.30E-02
Milk	4.75E-01	3.38E-01	3.28E-01	4.62E-01	2.24E-01
Water	5.98E+01	4.22E+01	3.91E+01	5.26E+01	2.74E+01
Freshwater Fish	4.23E+01	2.83E+01	2.31E+01	2.57E+01	1.67E+01
Total Ingestion Dose	1.20E+02	8.24E+01	7.33E+01	9.38E+01	5.11E+01
Total External Dose	2.95E-01	3.44E-01	4.16E-01	3.81E-01	5.96E-01
Total Effective Dose	1.20E+02	8.27E+01	7.38E+01	9.42E+01	5.17E+01

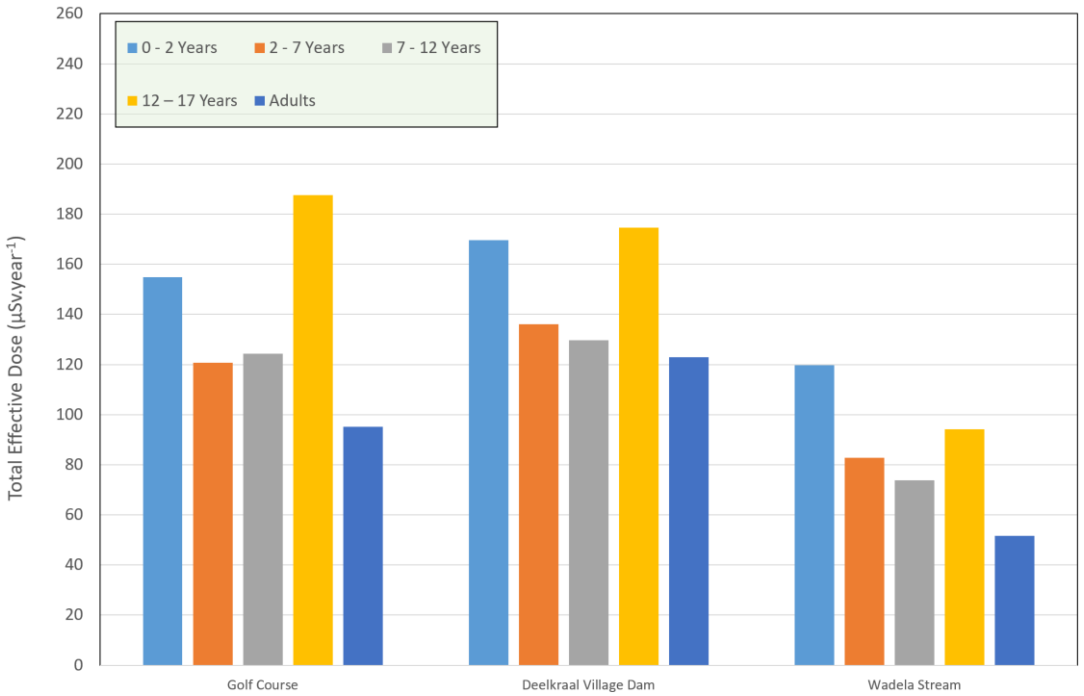


Figure 6.1 Summary of the total effective doses calculated for the different age groups for the data presented in Table 6.2 to Table 6.4.

Another aspect to note is that, for the evaluation, the assumed irrigation period to account for increased radionuclide concentrations in soil was conservatively set at 75 years. As the irrigation period increases, the resulting total effective dose will also increase with time but will only reach significant levels over long timescales. Figure 6.2 illustrates the effect of extended irrigation periods on the dose received by the different age groups.

The simulation was performed for 100,000 years. Although such a long period includes many uncertainties, the conservative extrapolation is performed for illustrative purposes and should not be regarded as an absolute prediction of the potential dose. Because a logarithmic scale is used for the time axis, the results in Figure 6.2 are shown from year 10 onward. The values for years 0 to 10 remain virtually constant. Figure 6.2 illustrates that even after 1,000 years, the potential total effective doses for all three sampling points remain below 350 µSv.year^{-1}.

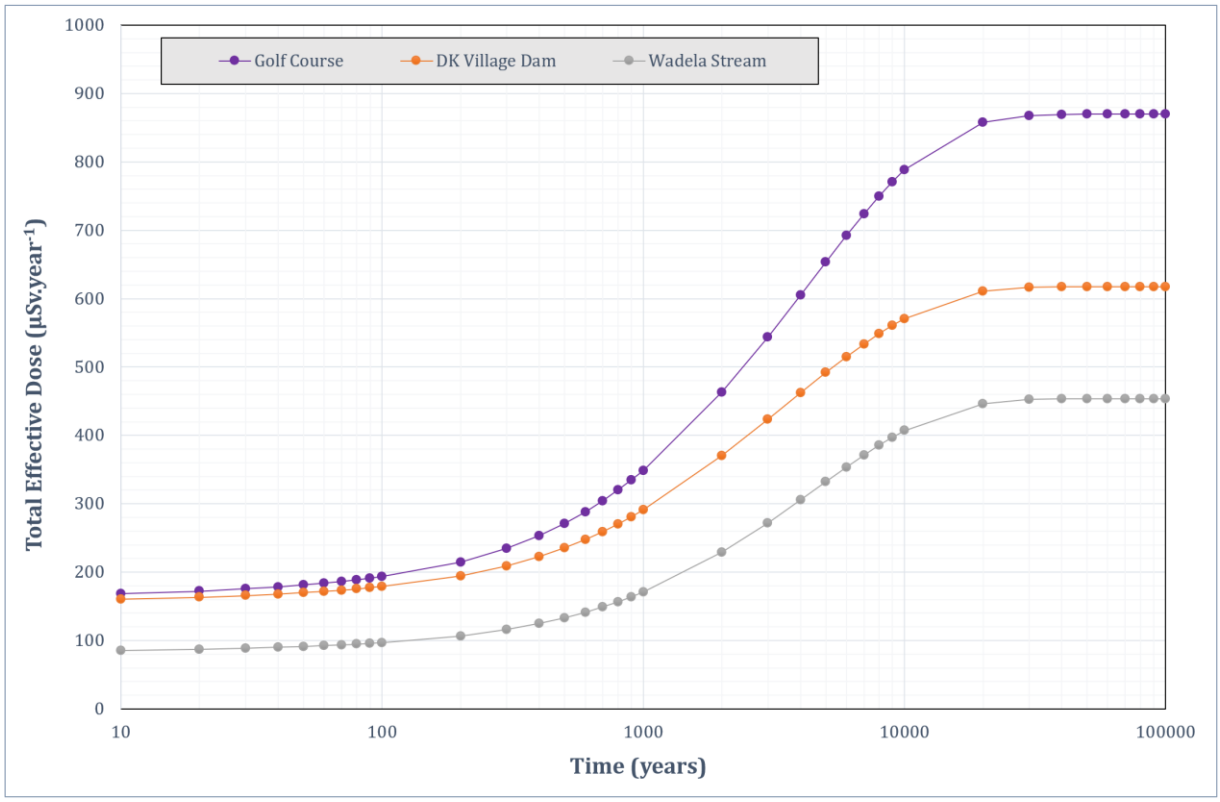


Figure 6.2 **Graph showing the increase in total effective dose to the different age groups due to continuous irrigation with water with radiological properties listed in Table 6.1.**

6.2.2.4 Conclusion

It can thus be concluded that, subject to very conservative assumptions, the surface water resources currently observed near the Project would not result in total effective doses to members of the public exceeding 250 µSv.year^{-1}. However, this is regardless of whether the radionuclides are from mining-related activities or natural background radiation.

6.2.3 Groundwater Pathway

6.2.3.1 General

Figure 3.53 shows the approximate locations of the groundwater monitoring points near the Project, while Table 6.5 summarises the radioanalysis results of groundwater sampling points available for the Project area as reported in detail in Section 3.8. It consists of historical results from four sampling points.

6.2.3.2 Dose Assessment

The data presented in Table 6.5 are used to assess the potential radiological dose to members of the public who utilise groundwater for household and subsistence agricultural practices. However, as indicated earlier, this is a conservative "what if" evaluation and must be done with care.

Table 6.5 Summary of the average radiological monitoring data for groundwater samples collected in the vicinity of the Project from AquiSim (2023).

Radionuclide	Groundwater Sampling Point			
	MBH 14	MBH 15	MBH 16	MBH 17
	$mBq.L^{-1}$			
U-238	56.1	29.1	55.5	24.7
U-234	197	71.1	100	62.7
Th-230	13	89.3	19.6	16
Ra-226	132	93.1	57.6	40.8
Pb-210	74.2	16	37	67.9
Po-210	74.2	16	37	67.9
U-235	2.58	1.34	2.55	1.14
Th-227	13.8	16.3	6.3	20.9
Ra-223	-1.9	-3.9	-2.4	-2.6
Th-232	5.24	17.5	6.82	12.3
Th-228	17.2	29.1	6.73	11.4
Ra-224	4.47	6.4	0.92	5.06

As for surface water, the dose assessment is performed for the conditions consistent with a Subsistence Agricultural Exposure Condition. This public exposure condition is the most conservative and, therefore, also covers the conditions defined for smaller-scale residential food cultivation activities. For the Subsistence Agricultural Exposure Condition, it is assumed that the farmer and his family consume water, soil, fruit, cereal, poultry, milk, eggs, meat (mutton and beef), as well as leafy and root vegetables at 100% of the annual ingestion rates presented in RG-002 (NNR, 2013).

Furthermore, it is assumed that the water source is sufficient to sustain a farm system annually. The contribution from external gamma radiation is through water immersion (e.g., bathing and swimming) and groundshine following deposition. A 75-year irrigation period was assumed for the analysis.

6.2.3.3 Results

Table 6.6 to Table 6.9 present the estimated total effective dose values for the groundwater monitoring data listed in Table 6.5, while Figure 6.3 summarises the total effective doses calculated for the different age groups for each of these points.

The results presented in Table 6.6 to Table 6.9 and Figure 6.3 indicate that, in general, the contribution from external exposure is insignificant compared to that from ingestion of water, crops, and animal products. As expected, the contribution of direct water ingestion is the most significant exposure route (between 75 and 79% of the total effective dose). Note that the results presented here include the contribution from natural background radiation. Most of the results are relatively low, below 150 $\mu Sv.year^{-1}$, and notably lower than those for the surface water sampling points presented in Figure 6.1.

Table 6.6 Total effective dose induced using water from MBH14 for household and subsistence farming purposes.

Ingestion Dose in µSv.year[1]					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	8.85E-01	6.59E-01	7.59E-01	1.38E+00	4.23E-01
Meat (Poultry)	7.00E-01	4.71E-01	3.73E-01	3.95E-01	3.29E-01
Meat (Mutton)	1.29E+00	1.01E+00	1.10E+00	1.76E+00	7.96E-01
Eggs	2.78E-01	1.88E-01	1.50E-01	1.60E-01	1.34E-01
Cereal (Grain)	3.79E+00	3.00E+00	3.30E+00	5.46E+00	2.32E+00
Root Vegetables	7.51E+00	5.77E+00	7.41E+00	1.49E+01	3.71E+00
Leafy Vegetables	8.07E+00	6.20E+00	7.34E+00	1.32E+01	4.02E+00
Fruits	4.62E+00	3.58E+00	4.16E+00	7.33E+00	2.45E+00
Soil (Cropland)	2.68E-01	2.12E-01	2.33E-01	3.84E-01	1.64E-01
Soil (Garden)	2.67E-01	2.11E-01	2.32E-01	3.83E-01	1.63E-01
Soil (Pasture)	2.67E-01	2.11E-01	2.32E-01	3.83E-01	1.63E-01
Milk	9.51E-01	7.35E-01	8.46E-01	1.46E+00	5.51E-01
Water	1.16E+02	9.17E+01	1.01E+02	1.66E+02	7.08E+01
Total Ingestion Dose	1.45E+02	1.14E+02	1.27E+02	2.13E+02	8.60E+01
Total External Dose	2.15E+00	2.51E+00	3.04E+00	2.78E+00	4.35E+00
Total Effective Dose	1.47E+02	1.16E+02	1.30E+02	2.16E+02	9.03E+01

Table 6.7 Total effective dose induced using water from MBH15 for household and subsistence farming purposes.

Ingestion Dose in µSv.year[1]					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	6.49E-01	4.79E-01	5.75E-01	1.02E+00	2.57E-01
Meat (Poultry)	4.05E-01	2.80E-01	2.31E-01	2.58E-01	2.12E-01
Meat (Mutton)	7.62E-01	6.01E-01	6.74E-01	1.10E+00	4.71E-01
Eggs	1.62E-01	1.13E-01	9.35E-02	1.06E-01	8.71E-02
Cereal (Grain)	2.60E+00	2.07E+00	2.32E+00	3.76E+00	1.56E+00
Root Vegetables	6.55E+00	4.91E+00	6.35E+00	1.19E+01	2.45E+00
Leafy Vegetables	5.06E+00	3.82E+00	4.77E+00	8.65E+00	2.06E+00
Fruits	2.96E+00	2.26E+00	2.75E+00	4.85E+00	1.37E+00
Soil (Cropland)	1.84E-01	1.47E-01	1.64E-01	2.65E-01	1.11E-01
Soil (Garden)	1.83E-01	1.47E-01	1.63E-01	2.64E-01	1.10E-01
Soil (Pasture)	1.83E-01	1.46E-01	1.63E-01	2.64E-01	1.10E-01
Milk	6.93E-01	5.32E-01	6.31E-01	1.07E+00	3.59E-01
Water	7.89E+01	6.30E+01	7.01E+01	1.13E+02	4.74E+01
Total Ingestion Dose	9.93E+01	7.85E+01	8.89E+01	1.47E+02	5.66E+01
Total External Dose	9.78E-01	1.14E+00	1.38E+00	1.26E+00	1.98E+00
Total Effective Dose	1.00E+02	7.96E+01	9.03E+01	1.48E+02	5.86E+01

Table 6.8 Total effective dose induced using water from MBH16 for household and subsistence farming purposes.

Ingestion Dose in µSv.year[1]					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	4.95E-01	3.59E-01	3.88E-01	6.69E-01	2.29E-01
Meat (Poultry)	6.13E-01	4.01E-01	3.07E-01	3.06E-01	2.60E-01
Meat (Mutton)	6.55E-01	5.11E-01	5.47E-01	8.66E-01	4.04E-01
Eggs	2.42E-01	1.59E-01	1.22E-01	1.23E-01	1.04E-01
Cereal (Grain)	1.86E+00	1.46E+00	1.58E+00	2.60E+00	1.13E+00
Root Vegetables	3.45E+00	2.65E+00	3.38E+00	6.82E+00	1.76E+00
Leafy Vegetables	3.84E+00	2.95E+00	3.46E+00	6.20E+00	1.94E+00
Fruits	2.21E+00	1.71E+00	1.97E+00	3.46E+00	1.19E+00
Soil (Cropland)	1.31E-01	1.03E-01	1.11E-01	1.82E-01	7.91E-02
Soil (Garden)	1.30E-01	1.02E-01	1.11E-01	1.81E-01	7.89E-02
Soil (Pasture)	1.30E-01	1.02E-01	1.11E-01	1.81E-01	7.88E-02
Milk	4.80E-01	3.71E-01	4.18E-01	7.09E-01	2.87E-01
Water	5.66E+01	4.45E+01	4.81E+01	7.86E+01	3.42E+01
Total Ingestion Dose	7.08E+01	5.53E+01	6.06E+01	1.01E+02	4.17E+01
Total External Dose	1.04E+00	1.21E+00	1.47E+00	1.34E+00	2.10E+00
Total Effective Dose	7.19E+01	5.66E+01	6.21E+01	1.02E+02	4.38E+01

Table 6.9 Total effective dose induced using water from MBH17 for household and subsistence farming purposes.

Ingestion Dose in µSv.year[1]					
Pathway	0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adults
Meat (Cattle	6.66E-01	5.04E-01	5.95E-01	1.11E+00	3.33E-01
Meat (Poultry)	3.13E-01	2.11E-01	1.69E-01	1.81E-01	1.49E-01
Meat (Mutton)	9.37E-01	7.27E-01	8.05E-01	1.33E+00	5.28E-01
Eggs	1.24E-01	8.37E-02	6.71E-02	7.21E-02	5.99E-02
Cereal (Grain)	3.17E+00	2.52E+00	2.76E+00	4.55E+00	1.92E+00
Root Vegetables	5.98E+00	4.61E+00	5.93E+00	1.21E+01	3.06E+00
Leafy Vegetables	6.77E+00	5.22E+00	6.14E+00	1.11E+01	3.43E+00
Fruits	3.82E+00	2.96E+00	3.43E+00	6.07E+00	2.02E+00
Soil (Cropland)	2.27E-01	1.80E-01	1.97E-01	3.22E-01	1.37E-01
Soil (Garden)	2.26E-01	1.80E-01	1.96E-01	3.21E-01	1.37E-01
Soil (Pasture)	2.26E-01	1.80E-01	1.96E-01	3.21E-01	1.37E-01
Milk	6.70E-01	5.18E-01	6.12E-01	1.10E+00	3.74E-01
Water	9.83E+01	7.82E+01	8.51E+01	1.39E+02	5.95E+01
Total Ingestion Dose	1.21E+02	9.61E+01	1.06E+02	1.78E+02	7.17E+01
Total External Dose	1.92E+00	2.23E+00	2.70E+00	2.48E+00	3.88E+00
Total Effective Dose	1.23E+02	9.83E+01	1.09E+02	1.80E+02	7.56E+01

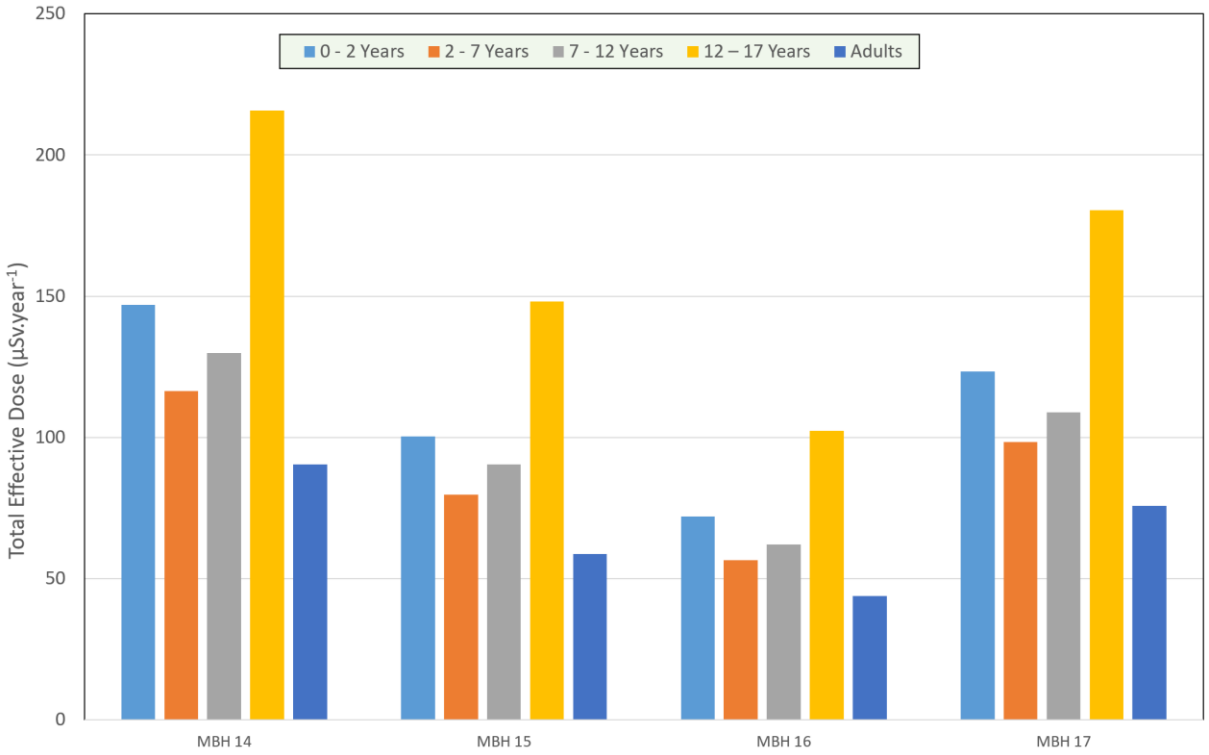


Figure 6.3 **Summary of the total effective doses calculated for the different age groups for the data presented in Table 6.6 to Table 6.9 as their only source of water to sustain a subsistence farm.**

Using the analysis results in Table 6.5 to calculate the total effective dose for a Subsistence Agricultural Exposure Condition, therefore, confirms that the potential contribution of groundwater as a water source is low compared with the dose limit or dose constraint, especially given the very conservative nature of the exposure condition.

As for the surface water pathway, Figure 6.4 illustrates the effect of an extended irrigation period on the dose received by the adult age group under the Subsistence Agricultural Exposure Condition, extrapolated over 100,000 years. Here too, the results are shown from year 10 on a logarithmic scale. Although the long simulation period used in this analysis introduces many uncertainties, a conservative extrapolation is performed for illustrative purposes. It should not be regarded as an absolute prediction of the potential dose. Figure 6.4 illustrates that after 1,000 years, the potential total effective doses for all four sampling points remain below 600 µSv.year^{-1}.

6.2.3.4 Conclusion

It can be concluded that, subject to very conservative assumptions, the groundwater resources currently observed near the Project would not pose a total effective dose to members of the public exceeding 250 µSv.year^{-1}. This is regardless of whether the radionuclides are from mining-related activities or natural background radiation.

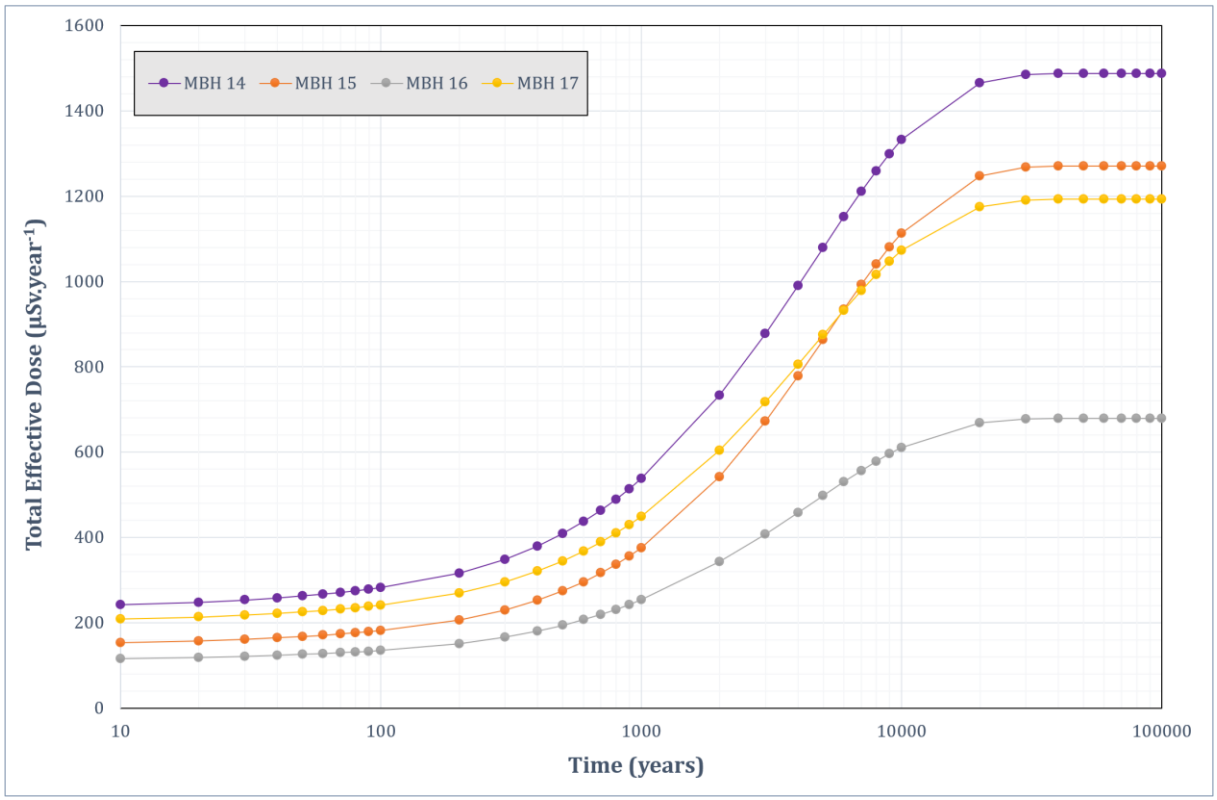


Figure 6.4 **Graph showing the increase in total effective dose to the different age groups due to continuous irrigation with water with radiological properties listed in Table 6.5.**

6.3 Cumulative Radiological Impact

On a local scale, it can be noted that the Project RPSA calculated the total effective dose to members of the public from all relevant exposure pathways included in the public radiation exposure conditions defined for the assessment. To the extent justified, the results, therefore, include the cumulative contribution from all exposure routes (e.g., inhalation, ingestion, and external gamma radiation).

On a regional scale, it can be noted that the results presented in Section 5 represent only the contribution from the Project to the total effective dose to members of the public. The national safety standards and associated regulatory compliance criteria make it clear that members of the public should be protected from *all* contributing sources or operations. In terms of national and international regulations, the total effective dose from all contributing sources should be below 1 mSv.year^{-1} (or 1,000 µSv.year^{-1}). The national safety standards also make provision for the application of a dose constraint of 0.25 mSv.year^{-1} (or 250 µSv.year^{-1}) for each CoR holder.

Therefore, for the cumulative contribution from other authorised facilities and operations, the public dose limit applies, whereas for facility-specific assessments the dose constraint is more applicable, especially to address multiple contributions. Based on the results presented in the Project RPSA, it was argued that it is unlikely that the public dose limit would be exceeded in areas where more than one authorised facility or operation is present.

6.4 Variations in Public Exposure Conditions

6.4.1.1 General

The public exposure conditions evaluated as part of the Project RPSA were defined following a systematic Source–Pathway–Receptor analysis approach, as reported in Section 4.2. An attempt was made to be comprehensive while also limiting the number of exposure conditions to a select few, since it is virtually impossible to define an exposure condition for every individual member of the public. The test of whether a discrete set of exposure conditions is comprehensive is whether individual members of the public can relate to at least one of the defined exposure conditions. In most cases, the defined condition will be conservative.

6.4.2 Variation in the Defined Exposure Conditions

Two public exposure conditions were defined in Section 4 for the Project RPSA, namely a Residential Area Exposure Condition and a Commercial Agricultural Exposure Condition. An attempt was made to be cautiously realistic in their definition, which means that variations can be expected.

For example, some members of the public residing in residential areas may not maintain a household garden. Their level of radiation exposure will thus be less than the calculated values presented for the Residential Area Exposure Condition. Similarly, members of the public may feel they can consume a wider variety of products at a rate exceeding the 50% specified for the Residential Area Exposure Condition. This means their radiation exposure is closer to that of the Commercial Agricultural Exposure Condition, which accounts for a wider range of ingestion pathways at higher ingestion rates. Another exposure condition might be that of an area dweller or a business owner. These groups will be subject only to inhalation and external gamma radiation (cloudshine), which are below the Residential Area Exposure Condition.

Consequently, the exposure conditions were defined as broadly as possible to describe the site-specific conditions in the area. Also, the Commercial Agricultural Exposure Condition is very conservative. It includes all potential exposure routes (i.e., inhalation, ingestion, and external exposure) and the maximum exposure factors (i.e., exposure periods and ingestion rates for all products). One would, therefore, expect that any variation in the public exposure condition would be less than the total effective doses presented in Section 5.3.7.

6.4.3 Alternative Exposure Conditions

The two public exposure conditions defined and evaluated in the Project RPSA are considered comprehensive and representative of a wide range of site-specific conditions. It was also argued that variations are expected, but that they will result in a lower radiological impact than that considered in the assessment.

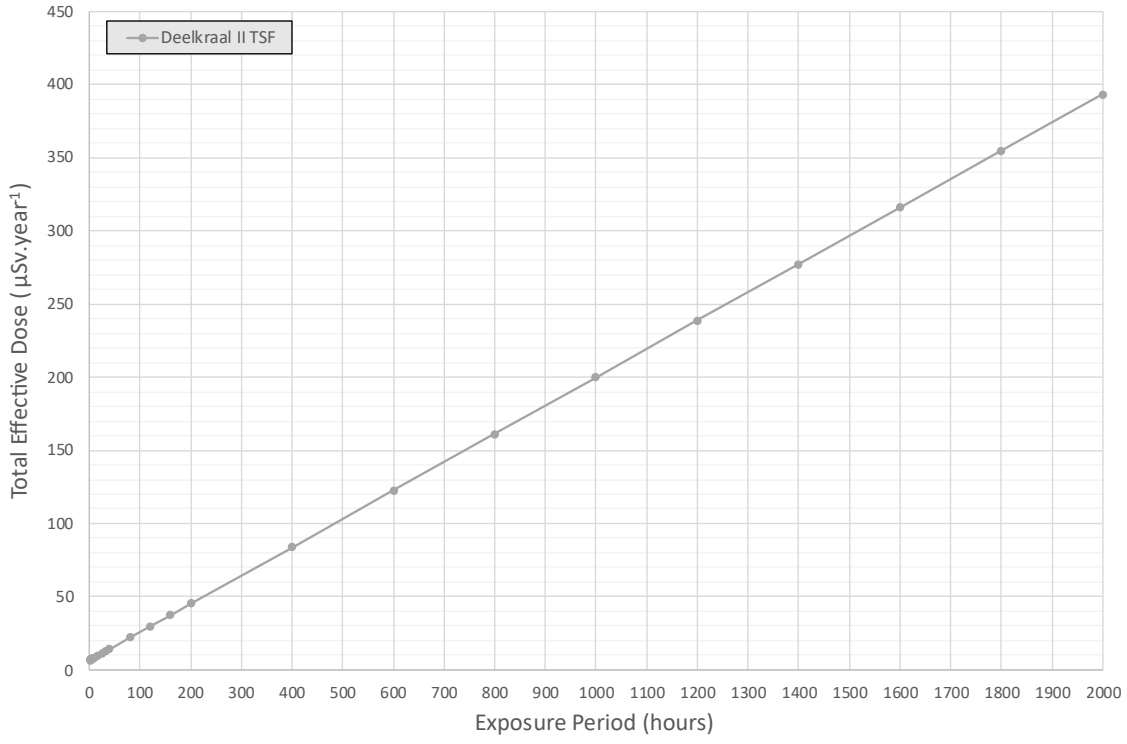
For example, the Source–Pathway–Receptor analysis suggests that an alternative public exposure condition could be one induced by accidents or incidents, such as pipeline bursts or other water or tailings spills into the environment. Section 4 describes in detail how these conditions are best handled and treated as part of the emergency response and other programmes within the radiation management plan. Several factors determine the potential level of public radiation exposure, making it difficult, if not impossible, to provide a general assessment, especially given the Project's widespread and diverse nature. These include:

- What was spilt (i.e., water or tailings) and what is the activity concentration of the water or tailings material that was spilt;

- Where the spillage took place (i.e., open field or at or near a surface water body), how long the spillage lasted and the lateral extent (area) that was contaminated; and
- How long is the area left unattended before remedial action is taken, and is there a possibility that members of the public could access the area?

It is thus clear that every spill would be different and would have a different radiological impact. However, one can assume that, for the tailings material considered in this assessment, the absolute maximum radiological impact would be less than the total effective doses calculated for the facilities presented in Section 5.3.7. To evaluate the potential radiological impact of a tailings spill from the Deelkraal II TSF, the following hypothetical exposure conditions were assumed. Following the spillage of tailings material, it is assumed that an area of 1 ha (100m x 100m) is covered with a 0.5 m thick layer of tailings material. Members of the public have access to the area and, depending on the period of exposure, may be exposed to dust inhalation, external gamma radiation, and radon gas inhalation.

Assuming a conservative set of parameter values to calculate the radon exhalation rate from the tailings layer and the airborne dust concentration, Figure 6.5 presents the total effective dose for the Deelkraal II TSF as a function of the exposure period. The total effective dose is predominantly driven by the Ra-226 concentration in the tailings material and, consequently, by the radon inhalation dose (see Table 3.26 and Table 3.27). From Figure 6.5, an exposure period of fewer than 1,200 hours per year (outside exposure) will still result in an effective dose of less than 250 µSv.year^{-1}.



c

Figure 6.5 Total effective dose for the Deelkraal II TSF as a function of the exposure period.

Note that these results should be treated with caution, as they reflect hypothetical conditions. There is no justification to think members of the public will spend so much time on a tailings spillage area. However, the results emphasise the need to clean a contaminated area as soon as possible to limit potential public exposure.

6.5 Variation in Parameter Values

6.5.1 Human Consumption Values

The human consumption rates used in the Project RPSA are based on those proposed in RG-002 (NNR, 2013). Compared with literature values, some of these values are high and conservative. This means that using more realistic values will reduce the calculated ingestion doses. Since most of the calculated ingestion doses across the different exposure conditions are relatively low, lower consumption rates will further reduce them (linearly).

One exception is probably the grain ingestion rate, which was reduced to 10% of the value specified in RG-002. Using a 100% grain consumption rate will significantly increase the grain ingestion dose. However, this will not affect the general conclusions regarding the exposure conditions defined for the Project RPSA. Note that the grain consumption rate was reduced to 10% of the RG-002 specified value since the proposed value is unrealistically high in a total diet.

On the other hand, assuming 100% grain consumption alongside all other ingestion pathways is unrealistic given the amount of food a human being can consume in a year. Under these conditions, the consumption rate of other products will have to be drastically reduced to be realistic, given the amount of food that humans across all groups can consume annually.

6.5.2 Dust Deposition Period

The dose calculations for the different exposure conditions were performed assuming a 75-year deposition period, which was considered realistic given the history of the Project area. The dose assessment models assumed a buildup of activity on the soil surface over this period, which, by implication, influences the total effective dose.

One can thus assume that the surface-soil concentration will continue to increase steadily over time. Experience shows that the rate of build-up increases until about 2,000 years, after which equilibrium is reached with removal processes such as radiological decay and leaching. Over this period, the ingestion doses could increase by more than threefold, accompanied by increased uncertainties. The effect of continued irrigation on the total effective dose is illustrated and discussed in Section 6.2, which is similar to that of continuous deposition of contaminated dust.

6.5.3 Groundwater Pathway Parameters

6.5.3.1 General

The *System Level* evaluation of the groundwater pathway presented in Section 5.2 assumed conservative parameter values to evaluate the leaching and migration of naturally occurring radionuclides through the Deelkraal II TSF and underlying hydrogeology (i.e., unsaturated and saturated zones). The results show that the groundwater pathway is highly unlikely to make a significant contribution within the next 10,000 years.

Presented here is an evaluation of the sensitivity of selected parameter values used in the groundwater pathway analysis. For this purpose, the analysis results for the Deelkraal II TSF for the 0 to 2 years age group are used as a reference since it is the largest potential source that will remain at the surface after the operational period of the Project. The 0 to 2 years age group is the highest exposure group for the TSF (see Figure 5.4).

6.5.3.2 Source Duration

The analysis in Section 5.2 assumed that the Deelkraal II TSF remains at the surface for 1,000 years. It is viewed as conservative, though it is unclear how long it will last. Figure 6.6 shows that water ingestion doses will increase the longer it remains a source of naturally occurring radionuclides leaching into groundwater. In this case, the water ingestion dose increases to approximately 360 µSv.year^{-1} for a source duration of 3,000 years.

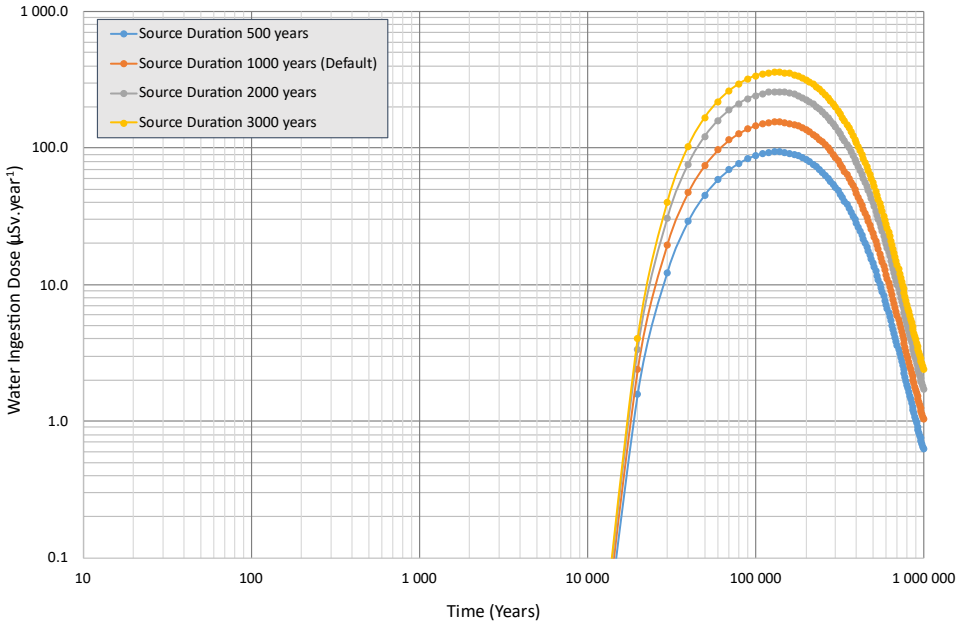


Figure 6.6 The simulated water ingestion dose for the 0 to 2 years age group using different source durations for the Deelkraal II TSF.

6.5.3.3 Distribution Coefficients (K_d-values)

The analysis in Section 5.2 used Kd-values that are significantly lower than the values published in RG-002 (NNR, 2013) (see Table 5.3). High K_d-values are conservative for bioaccumulation of activity in the soil layer following irrigation deposition. In contrast, lower K_d-values are conservative for transport processes in the source area and the aquifer. Figure 6.7 shows that the results are sensitive to changes in the Kd values used and significantly influence the maximum water ingestion dose and its time. For values 10 times smaller, the water ingestion dose can increase to 450 µSv.year^{-1}, with the peak observed only after 80,000 years.

6.5.3.4 Hydraulic Conductivity

It is expected that the hydraulic conductivity (K) across the central and eastern parts of the Witwatersrand basin may vary significantly at local and regional scales. The hydraulic conductivity of 0.085 m.day^{-1} used in the analysis in Section 5.2 for the underlying aquifer is conservative. Figure 6.8 shows that a higher hydraulic conductivity will reach the abstraction borehole earlier but at a lower concentration and dose (42 µSv.year^{-1} after 20,000 years). A lower hydraulic conductivity results in a higher peak dose at a much later time (275 µSv.year^{-1} after 600,000 years).

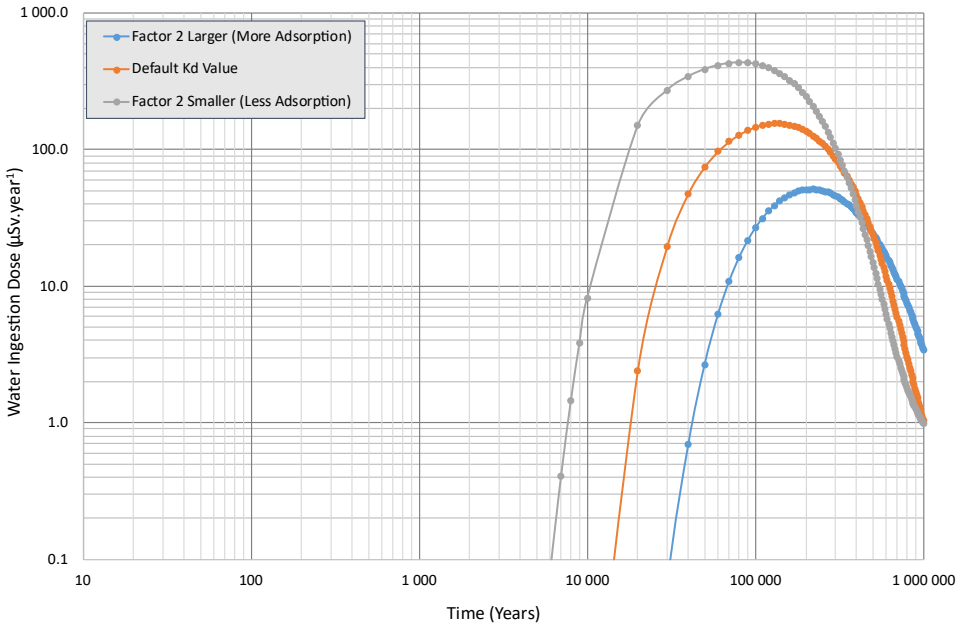


Figure 6.7 **The simulated water ingestion dose to the 0 to 2 years age group using different Kd-values for the Deelkraal II TSF and underlying hydrogeology.**

6.5.3.5 Distance to the Abstraction Borehole

A distance of 500 m to an abstraction borehole was assumed for the analysis in Section 5.2. As illustrated in Figure 6.9, an increase or decrease in distance merely shifts the detection time earlier or later. However, the peak remains approximately constant at 160 µSv.year^{-1}.

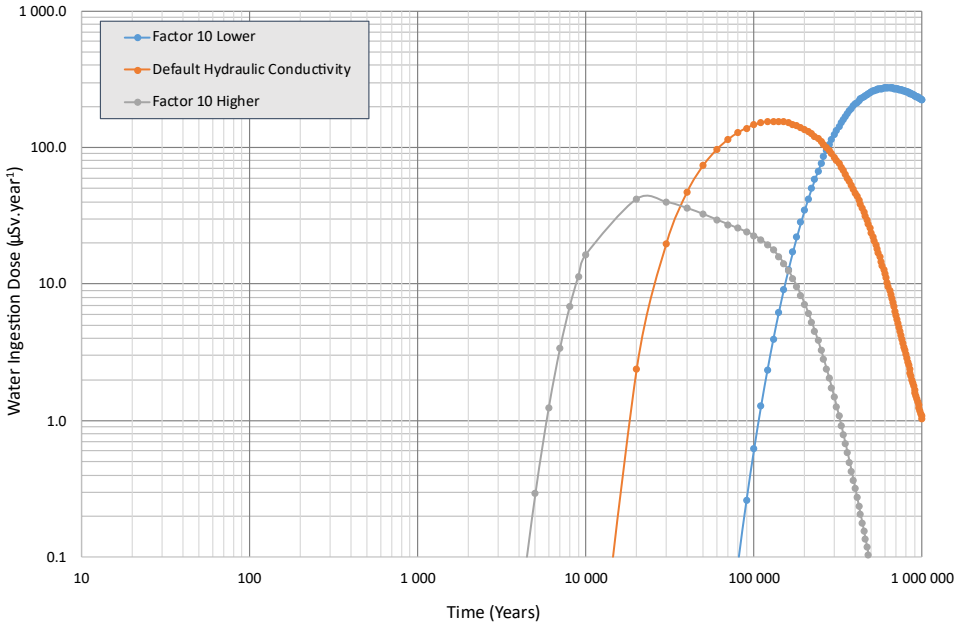


Figure 6.8 **The simulated water ingestion dose to the 0 to 2 years age group using different hydraulic conductivity (K) values for the underlying hydrogeology.**

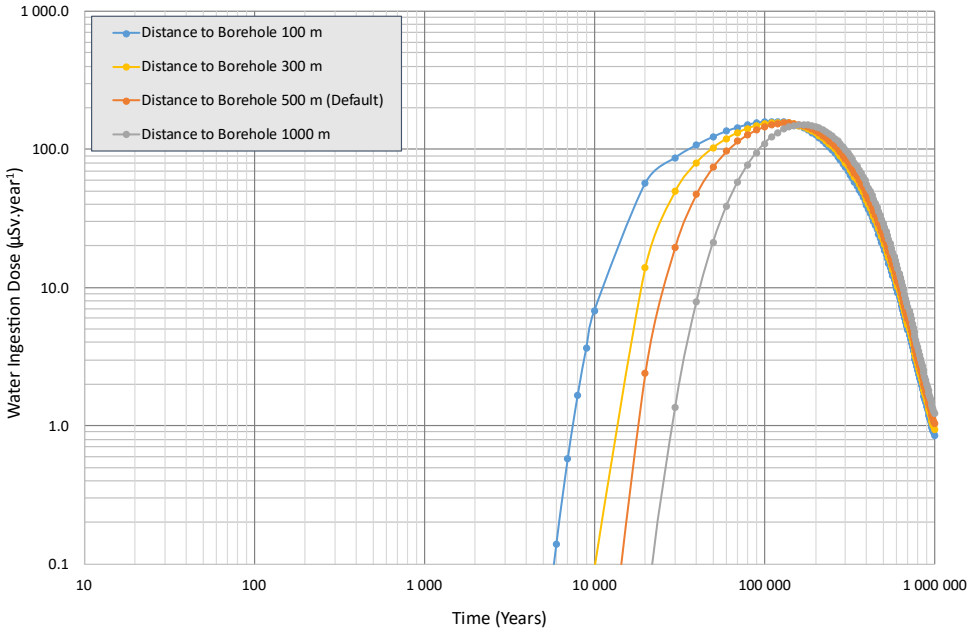


Figure 6.9 **The simulated water ingestion dose to the 0 to 2 years age group using different distances from the Deelkraal II TSF to an abstraction borehole.**

6.5.3.6 Aquifer Thickness

An aquifer thickness of 20 m was assumed for the analysis in Section 5.2. As illustrated in Figure 6.10, a decrease in aquifer thickness results in a higher dose, since less water is available to dilute the infiltrating contaminated water in the aquifer (mixing). Conversely, a thicker aquifer provides more water to dilute the plume, resulting in lower doses. As expected, the time of the maximum remains approximately constant.

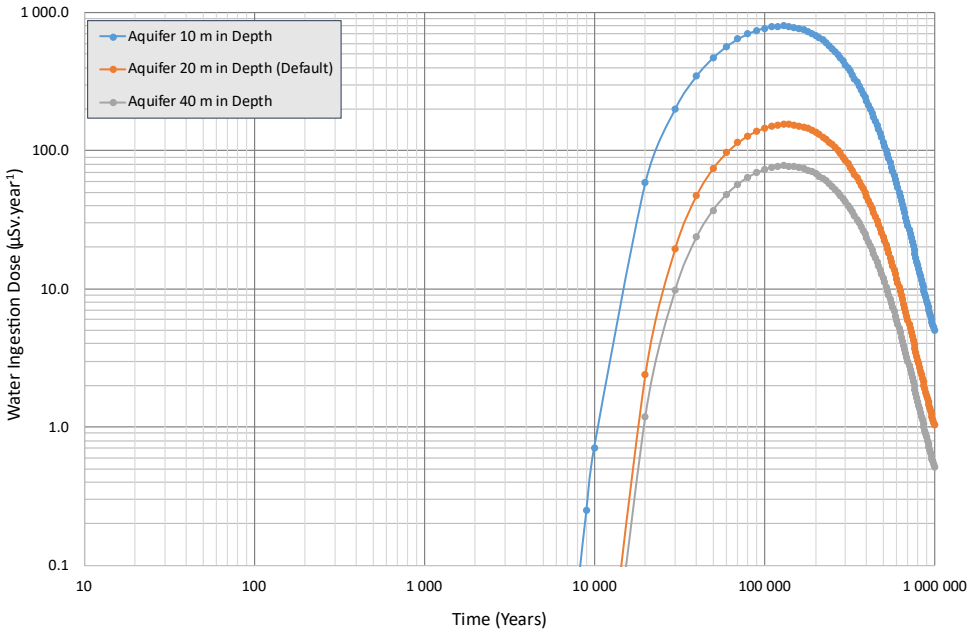


Figure 6.10 **The simulated water ingestion dose to the 0 to 2 years age group using different aquifer depths underneath the Deelkraal II TSF.**

6.5.3.7 Unsaturated Zone Thickness

A 5 m unsaturated zone thickness was assumed for the analysis in Section 5.2. As illustrated in Figure 6.11, an increase in the unsaturated zone thickness results in a similar dose but a later detection time. An unsaturated zone thickness of 2 m results in a higher dose, but at detection times similar to those in the analysis in Section 5.2.

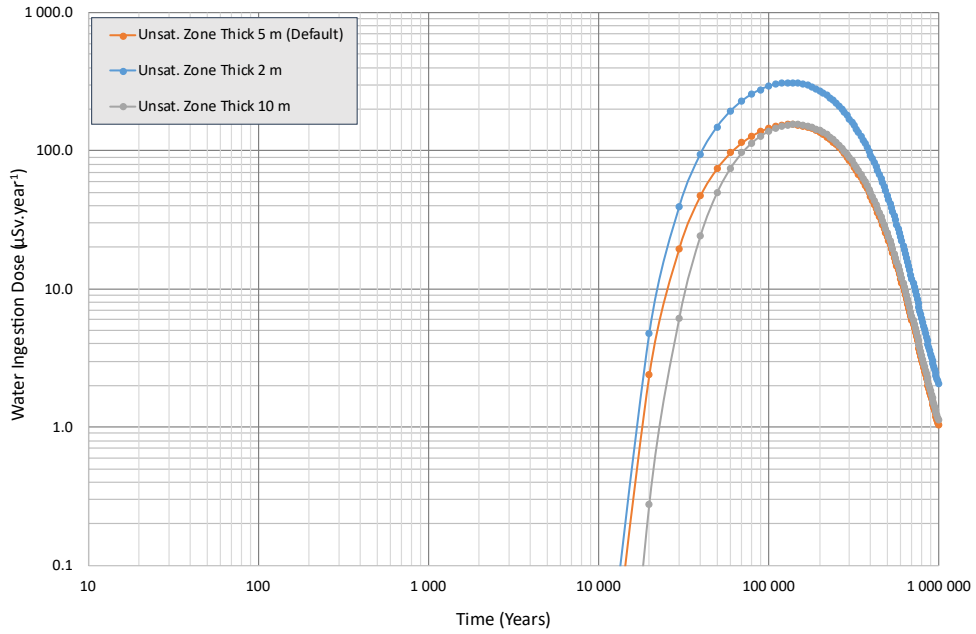


Figure 6.11 The simulated water ingestion dose to the 0 to 2 years age group using different unsaturated zone thicknesses below the Deelkraal II TSF.

7 Impact Assessment

7.1 General

The purpose of this section is to present the radiological impact assessment rating for the Project. Section 2.3.7.3 presented the criteria for the impact assessment rating as an endpoint. The basis for the impact assessment rating is the quantitative and qualitative assessment of the potential radiological consequences to receptors identified for the Project, as presented in Section 5.

The impact assessment rating distinguishes between the Project's different phases (i.e., construction, operation, and post-closure) and the contributions of the atmospheric, surface water, and groundwater pathways, as appropriate. The reason for the latter is that the timescales over which the pathways contribute to a potential radiological impact on members of the public differ. Where required, mitigation measures are proposed for activities during the different Project phases, followed by an impact rating for the revised (mitigated) conditions.

The section is structured as follows. Section 7.2 presents the radiological impact expected during the construction phase. The most significant radiological impact is expected during the operational phase, as presented in Section 7.3, followed by the post-closure phase presented in Section 7.4. Section 7.5 discusses any cumulative impact that might be of concern.

7.2 Construction Phase

As part of the Project, the Kusasalethu TSF and Deelkraal TSF will be reclaimed. However, Deelkraal II TSF and additional infrastructure would need to be constructed. This includes upgrades to the associated pipeline infrastructure for transferring water and tailings material between the various entities and the plant.

Activities performed in these areas during the construction phase will not pose a radiological impact on the public, as they do not involve handling, processing, or releasing radioactive material into the environment *per se*. This means that the potential radiological impact on members of the public through the relevant pathway during the construction phase is negligible.

7.3 Operational Phase

7.3.1 General

The radiological impact assessment for the operational phase considers the potential contribution through all three environmental pathways (i.e., surface water, groundwater and atmospheric). However, due to the slow-moving nature of any radionuclide-contaminant plume originating from the Project facilities through the groundwater system, the potential radiological impact through the groundwater pathway will only occur during post-closure (see Section 7.4).

7.3.2 Activities

During the operational phase of the Project, the following activities were identified that may result in a radiological impact on members of the public:

- Exhalation and dispersion of radon gas from the dormant and operational TSFs.
- Emission and dispersion of particulate matter containing radionuclides from the operational TSFs.
- Reclamation of existing TSFs.

Table 7.1 summarises the activities associated with the operational phase that may have a potential radiological impact on the receptors identified for the Project.

Table 7.1 Summary of the activities and the impact of the activities during the operational phase of the Project.

Interaction	Impact
Exhalation and dispersion of radon gas into the atmosphere	Radon gas generated in the tailings due to the presence of Ra-226 will be exhaled into the atmosphere. Inhalation of the radon gas contributes to the total effective dose.
Emission and dispersion of particulate matter into the atmosphere	Wind erosion at the TSFs will emit particulate matter containing radionuclides into the atmosphere. Airborne dust (PM_{10}) and deposited dust (TSP) contribute to the total effective dose through inhalation, ingestion, and external radiation exposure.
Reclamation of existing TSFs	The reclamation of existing TSFs involves removing a source of radiation exposure to receptors identified for the Project, potentially reducing the total effective dose across all relevant exposure routes.

7.3.3 Exhalation and Dispersion of Radon Gases

7.3.3.1 Impact Description

During the operational phase and throughout the LoM, radon gas is generated in the TSFs due to the presence of Ra-226. This means that these gases are continuously exhaled from these facilities into the atmosphere.

Following the exhalation and subsequent dispersion of the radon gas into the atmosphere, inhalation of the airborne gas contributes to the total effective dose to receptors identified for the Project.

7.3.3.2 Management/Mitigation Measures

The management objective would first be to ensure that radiation exposure is below regulatory compliance criteria (i.e., the dose constraint) and, second, to optimise radiation protection by applying the ALARA principle (As Low As Reasonably Achievable, with economic and social factors taken into account).

The total effective dose from radon gas released from the TSFs is well below regulatory compliance criteria, indicating that, from a compliance perspective, no additional management or mitigation measures are required for radon inhalation. From a dose optimisation perspective, the following can be noted:

- The radon exhalation rate from the surface of tailings material is determined by several factors, of which moisture content is one. This means that, for the area at a TSF subject to retreatment, the radon exhalation rate will be reduced marginally. However, it is not effective to wet the TSF deep enough (2 to 4 m) to reduce the radon exhalation rate marginally.
- The most effective way to reduce radon exhalation rates for the Deelkraal II TSF is to provide a covering layer. This will increase the diffusion length, allowing radon progeny to decay before they are released from the tailings surface.

7.3.3.3 Impact Rating

Table 7.2 presents the impact significance rating for radon gas exhalation and dispersion during the Project's operational phase.

Table 7.2 Impact significance rating for the exhalation and dispersion of radon gas during the operational phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Exhalation and dispersion of radon gas to the atmosphere during the operational phase of the Project				
Pre-Mitigation					-2.75
Nature	-1	Likely to result in a negative impact	-5.5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of radon inhalation to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	3	The impact is reversible, but at significant time and cost to reduce the radon exhalation rate from the TSF.			
Probability	2	There is a low probability that the radon inhalation dose will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-2.75		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of radon inhalation to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	3	The impact is reversible, but at significant time and cost to reduce the radon exhalation rate from the TSF.			
Probability	1	It is improbable that the radon inhalation dose will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

7.3.4 Emission and Dispersion of Particulate Matter

7.3.4.1 Impact Description

During the operational phase, the TSF areas will serve as a source of windblown dust (i.e., wind erosion) to the atmosphere. These particulate-matter-containing radionuclides are dispersed into the environment via atmospheric pathways. The emission and subsequent dispersion of particulate matter into the atmosphere result in airborne radionuclide concentrations associated with PM_{10}, and soil radionuclide concentrations following the deposition of TSP. Through secondary pathways, the radionuclides in the soil may be

transferred to crops and animal products. Contributions to the total effective dose to receptors identified for the Project include inhalation of airborne dust, ingestion of contaminated soil, crops and animal products, and external gamma radiation through cloudshine and groundshine.

7.3.4.2 Management/Mitigation Measures

The management objective would first be to ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint) and, secondly, to optimise radiation protection by applying the ALARA principle.

The contribution of dust inhalation to the total effective dose is less than 2% (on average) at selected receptor locations across all age groups. The contribution of external exposure (cloudshine and groundshine) is effectively 5% (on average) of the total effective dose for all age groups at selected receptor locations. The contribution of animal and crop ingestion ranges from 55% to 75% of the total effective dose (on average) across all age groups at selected receptor locations, depending on the Public Exposure Condition.

In addition, the total effective dose at these locations is less than 80% of the public exposure dose constraint of 250 $\mu Sv.year^{-1}$ for the Residential Area Exposure Condition and approximately 50% less for the Commercial Agricultural Exposure Condition. Only the Farm 7 location for the Commercial Agricultural Exposure Condition is slightly above the dose constraint. This means that from a regulatory compliance perspective, no additional management or mitigation measures are required for any of the dust inhalation, external gamma radiation or ingestion pathways.

From a dose-optimisation perspective, the following mitigation measures can be implemented. These measures, which are in line with the measures proposed in the air quality impact assessment Airshed (2026), will contribute to a reduction in the total effective dose if applied for the duration of the operational period:

- Develop an air quality management plan for the Project, including air quality monitoring to ensure compliance at upwind and downwind locations; and
- Application of dust suppressants, i.e., Dust-A-Side, on exposed areas of the TSFs.
- Grassing of TSF side slopes and wet slurry deposition.

7.3.4.3 Impact Rating

Table 7.3 presents the impact significance rating for the emission and dispersion of radionuclide-containing particulate matter during the Project's operational phase.

7.3.5 Retreatment of Existing TSFs

7.3.5.1 Impact Description

One of the main objectives of the Project is the retreatment of the Kusasalethu and Deelkraal TSFs, which, by implication, means that the facility is removed from the surface. Once removed, and provided that the TSF footprint area is rehabilitated and cleaned up, the implication is that the source of radiation exposure to receptors identified for the Project is eliminated. Under these conditions, this will result in a reduction of the total effective dose induced by wind erosion and radon exhalation.

Table 7.3 Impact significance rating for the particulate matter emission and dispersion that contains radionuclides during the operational phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Emission and dispersion of particulate matter that contains radionuclides to the atmosphere during the operational phase of the Project				
Pre-Mitigation					-2.5
Nature	-1	Likely to result in a negative impact	-5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible, but at significant time and cost to reduce wind erosion from the TSF.			
Probability	2	There is a low probability that the contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-2.5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible, but at significant time and cost to reduce wind erosion from the TSF.			
Probability	1	It is improbable that the contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

7.3.5.2 Impact Rating

Table 7.4 presents the impact significance rating for the retreatment of existing TSFs during the operational phase of the Project.

Table 7.4 Impact significance rating for the retreatment of the existing TSFs during the operational phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Retreatment of the existing TSFs during the operational phase of the Project.				
Pre-Mitigation					+12
Nature	+1	Likely to result in a positive impact	+6		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter as the facility is removed from the surface			
Magnitude	2	Low. Facilities to be removed, but footprint areas to remain, which need to be rehabilitated			
Reversibility	3	The impact is reversible, but it would require significant time and cost to reduce the wind erosion from the TSF			
Probability	2	There is a low probability that the impact will occur			
Post Mitigation					
Nature	+1	Likely to result in a positive impact	+12		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter as the facility is removed from the surface			
Magnitude	3	Moderate. Facilities to be removed, but footprint areas to remain, which need to be rehabilitated			
Reversibility	3	The impact is reversible, but it would require significant time and cost to reduce wind erosion from the TSF			
Probability	3	There is a medium probability that the impact will occur			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

7.4 Post-Closure Phase

7.4.1 General

Before the actual closure of the Project and as part of the anticipated licensing conditions and requirements, a decommissioning and closure plan will be prepared for submission and approval by the regulatory authorities. Amongst others, this plan will define in detail all activities to be performed and how the associated radiological impact during the decommissioning and closure phase will be managed.

7.4.2 Activities

Considering that a decommissioning plan for the Project is not available at present, but will be defined and implemented as mentioned in Section 7.4, the following activities were identified that may result in a radiological impact on the receptors identified for the Project during the post-closure phase:

- Implementation of the approved decommissioning plan.
- Exhalation of radon gas and the emission of particulate matter (PM_{10} and TSP) that contain radionuclides from the remaining facilities (e.g., TSF).
- Leaching and migration of radionuclides from the remaining facilities (e.g., TSF).

Table 7.5 summarises the activities associated with the post-closure phase that may have a potential impact on the receptors identified for the Project.

Table 7.5 Summary of the activities and the impact of the activities during the post-closure phase.

Interaction	Impact
Implementation of the decommissioning plan	The decommissioning plan involves a site-wide effort to demolish, decontaminate, and remove all surface infrastructure that may contain or be contaminated with radionuclides. These areas, and any other contaminated areas, will be rehabilitated and cleaned for regulatory authority clearance.
Exhalation of radon gas and particulate matter from the remaining surface facilities (e.g., TSF) to the atmosphere	Radon gas generated in the remaining facilities (e.g., tailings material) due to the presence of Ra-226 will be exhaled into the atmosphere. Inhalation of the radon gas contributes to the total effective dose. Wind erosion at the remaining facilities will emit particulate matter containing radionuclides into the atmosphere. Airborne dust (PM_{10}) and deposited dust (TSP) contribute to the total effective dose through inhalation, ingestion, and external radiation exposure.
Leaching and migration of radionuclides from the TSF	Radionuclides will leach from the TSF into the underlying aquifer, after which they will migrate in the direction of the general groundwater flow. The abstraction and use of contaminated water contribute to the total effective dose through ingestion and potential external radiation exposure.

7.4.3 Implementation of the Decommissioning Plan

7.4.3.1 Impact Description

The implementation of the decommissioning plan will have a positive impact by ensuring that all surface infrastructure containing or contaminated with radionuclides is demolished, decontaminated (to the extent possible), and removed from the site, and that compliance with clearance criteria is demonstrated.

A gamma radiation survey, supplemented by full-spectrum radioanalysis of soil samples, will be conducted at the infrastructure sites, followed by appropriate rehabilitation and cleanup operations to obtain conditional or unconditional clearance from the regulatory authority. In addition, any area that may have become contaminated during or as a result of operational activities will be rehabilitated and cleaned up for conditional or unconditional clearance.

7.4.3.2 Impact Rating

Table 7.6 presents the impact significance rating for implementing the Project's decommissioning plan.

Table 7.6 Impact significance rating for the implementation of the decommissioning plan of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Implementation of the NNR-approved decommissioning plan of the Project				
Pre- and Post-Mitigation					16
Nature	1	Likely to result in a positive impact	16		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The effective implementation of the decommissioning plan will have an irreversible impact that will remain after the closure.			
Magnitude	4	The impact on members of the public will be high and widespread			
Reversibility	5	The implementation of a good decommissioning plan is irreversible			
Probability	4	There is a low probability that the secondary pathway induced by wind erosion will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

7.4.4 Exhalation of Radon Gas and Particulate Matter

7.4.4.1 Impact Description

During the post-closure phase, some facilities (e.g., TSFs) will remain at the surface and continue to pose radiation exposure risks to the public. These facilities will serve as sources of windblown dust (i.e., wind erosion) in the atmosphere during the post-closure period. During the same period, radon gas generated in the tailings materials due to the presence of Ra-226 will continue to be exhaled into the atmosphere.

The emission and subsequent dispersion of particulate matter into the atmosphere result in airborne radionuclide concentrations associated with PM_{10}, and soil radionuclide concentrations following the deposition of TSP. Through secondary pathways, the radionuclides in the soil may be transferred to crops and animal products. Contributions to the total effective dose to receptors identified for the Project include inhalation of the airborne dust, ingestion of contaminated soil, crops and animal products, and external gamma radiation through cloudshine and groundshine.

Following the exhalation and subsequent dispersion of the radon gas into the atmosphere, inhalation of the airborne gas contributes to the total effective dose to receptors identified for the Project.

7.4.4.2 Management/Mitigation Measures

The management objective would first be to ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint) and, secondly, to optimise radiation protection by applying the ALARA principle.

The total effective dose from windblown dust and radon gas released from the remaining facilities is well below the regulatory compliance criteria (dose constraint), indicating that, from a compliance perspective, no additional management or mitigation measures are required.

From a dose optimisation perspective, the following mitigation measures that are in line with the measures proposed by the air quality impact assessment Airshed (2026) can be applied for the post-closure phase:

- Vegetation of exposed areas of the TSFs to reduce wind erosion and/or the application of dust suppressants (e.g., Dust-A-Side);
- Clean-up and rehabilitation of contaminated footprint areas.

7.4.4.3 Impact Rating

Table 7.7 presents the impact rating for the exhalation, emission, and dispersion of radon gas and radionuclide-containing particulate matter during the post-closure phase of the Project.

7.4.5 Leaching and Migration of Contaminants from the Project TSF

7.4.5.1 Impact Description

From the commissioning of a TSF, radionuclides contained in the tailings material leach from the TSF to the underlying strata. Complex geochemical and hydrological processes control leaching rates, but leaching is generally slow. Once in the underlying strata, migration of these radionuclides is equally slow along the groundwater flow path.

Abstraction of groundwater for personal or agricultural purposes may result in radiological impacts on receptors identified for the Project through direct ingestion of water or, as secondary pathways, ingestion of crops and animal products. The radiological impact along the groundwater pathway only manifests itself during the post-closure period, hundreds to thousands of years after closure.

7.4.5.2 Management/Mitigation Measures

The management objective would first be to ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint) and, secondly, to optimise radiation protection by applying the ALARA principle.

The total effective dose from groundwater ingestion due to the TSF was hypothetically shown to be below the regulatory compliance criteria (i.e., dose limit), indicating that, from a compliance perspective, no additional management or mitigation measures are required.

From an optimisation of radiation protection perspective for the post-closure period, the following management/mitigation measures can be implemented if it is assumed that the facility remains at the surface:

- Implementation of a passive groundwater remediation system downstream of the TSF to capture the contaminant plume.

Note that active remediation systems, such as cut-off trenches or pump-and-treat systems, may also be effective in the short- to medium-term. However, the timescales of concern are beyond the range of active institutional control periods.

Table 7.7 Impact significance rating for the exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of the Project				
Pre-Mitigation					-2.5
Nature	-1	Likely to result in a negative impact	-5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for as long as the TSF is at the surface			
Magnitude	1	Minor. The contribution of dust and radon gas inhalation, as well as the dust deposition (and the subsequent secondary pathway) to the total effective dose, is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible, but at significant time and cost to reduce wind erosion from the TSF.			
Probability	2	There is a low probability that the contribution of radon inhalation, dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-2.5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible without incurring significant time and cost to reduce the wind erosion from the TSF.			
Probability	1	It is improbable that the contribution of radon inhalation, dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

Table 7.8 presents the impact significance rating for radionuclide leaching and migration from the TSF during the post-closure phase of the Project.

Table 7.8 Impact significance rating for the leaching and migration of radionuclides from the TSFs during the post-closure phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Leaching and migration of radionuclides from the TSF during the post-closure phase of the Project				
Pre-Mitigation					-6
Nature	-1	Likely to result in a negative impact	-6		
Extent	3	Exposure extent beyond the mining rights area into the immediate surroundings with agricultural land use conditions in the direction of flow			
Duration	5	The impact will occur for as long as the TSF is at the surface			
Magnitude	1	Minor. The impact is expected in the immediate surroundings, and for the defined exposure conditions, the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	3	The impact is reversible only by incurring significant time and cost to reduce radionuclide migration from the TSF into the environment.			
Probability	2	There is a low probability that the contribution of radionuclides released from the TSF into the environment will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-6		
Extent	3	Exposure extent beyond the mining rights area into the immediate surroundings with agricultural land use conditions in the direction of flow			
Duration	5	The impact will occur for as long as the TSF is at the surface			
Magnitude	1	Minor. The impact is expected in the immediate surroundings, and for the defined exposure conditions, the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible only by incurring significant time and cost to reduce radionuclide migration from the TSF into the environment.			
Probability	2	There is a low probability that the contribution of radionuclides released from the TSF into the environment will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

7.5 Cumulative Impact

The cumulative radiological impact of a mining operation can be assessed at different levels.

Firstly, the radiological safety assessment process considers the cumulative contributions from all relevant exposure pathways, including surface water, groundwater, and atmospheric pathways, as appropriate. This means that the radiological impact assessment includes the cumulative impact of the exposure pathways, as appropriate and justified.

Secondly, the radiological safety assessment process considers the cumulative contribution from all relevant exposure routes for each exposure pathway. These include inhalation of radon gas and dust, external gamma radiation (groundshine and cloudshine), and ingestion of soil, water, crops, and animal products, as appropriate and justified for each public exposure condition. This means that the radiological impact assessment includes the cumulative impact of the exposure routes, as appropriate and justified.

Thirdly, the radiological safety assessment process considers the cumulative contribution from all relevant sources of radiation exposure associated with the Project. These sources may vary across exposure pathways but include TSF and open-pit areas. This means that the impact assessment includes the cumulative impact of these sources, as appropriate and justified.

Finally, on a more regional scale, the assessment context accounts for cumulative impacts from all contributing operations (or practices) in the area, which may contribute to the total effective dose to members of the public. This is important because the public dose limit of 1,000 $\mu Sv.year^{-1}$ applies to all contributing sources and operations.

However, as stated in Section 2.3.4.7, the assessment's scope was limited to the Project. It did not provide for a regional assessment to evaluate the cumulative effects of all contributing operations. The total effective dose remained below the single-operation dose constraint, indicating that the cumulative impact from all operations will remain below the public dose limit.

8 Radiation Monitoring Programme

8.1 General

Within the broader radiation management plan, the purpose of the public Radiation Protection Programme (RPP) is to implement measures to ensure that members of the public are protected from potential exposure to ionising radiation arising from the Project. The regulatory authority-approved public RPP definition is based on the outcome of the comprehensive radiological public safety assessment. It typically includes a radiation monitoring programme, a surveillance programme and a control programme.

The purpose of this section is to define a radiation monitoring programme for the Project. The basis for the definition of the monitoring programme presented here is the outcome of the radiological impact assessment presented in this report, taking into consideration the radiological information available at present (see Section 3.8).

The section is structured as follows. Section 8.2 discusses the characterisation of the baseline conditions associated with the Project. Section 8.3 presents the proposed monitoring programme, while Section 8.4 presents the proposed monitoring locations.

8.2 Baseline Characterisation

The purpose of the radiological baseline characterisation programme is to establish the radiological conditions observed at the site and surroundings before the commissioning of the Project. No baseline characterisation has been done in the Project area yet. It should, to the extent possible, include soil, surface water, and groundwater samples, as well as an airborne environmental radon survey of the area using RGMs.

In addition to these sampling and analysis, it is proposed that a full gamma radiation and dose rate survey be conducted on a grid basis after site preparation and cleaning. Soil samples should again be collected for full-spectrum radioanalysis of the U-238, U-235, and Th-232 decay chains in the affected areas, at locations determined by the gamma radiation survey.

8.3 Monitoring Programme

The Project TSFs fall within the scope of CoR-28, which has an approved public Radiation Protection Programme (RPP) that provides for environmental monitoring and analysis to ensure that members of the public are adequately protected from environmental releases. The responsibility for implementing and executing the monitoring programme lies with the Radiation Protection Function (RP Function), which may include legally appointed personnel: a Radiation Protection Monitor (RPM), a Radiation Protection Officer (RPO), and a Radiation Protection Specialist (RPS).

Table 8.1 summarises the proposed monitoring programme for the Project aimed at public radiation protection.

Full-spectrum analysis is suitable for detailed dose analysis but is an expensive, time-consuming procedure; therefore, less frequent intervals are proposed. Total uranium and thorium analyses are relatively inexpensive and have fast turnaround times. These results will monitor variations in activity concentration over the monitoring period.

Significant variations in activity concentration over short periods are not expected in groundwater, unlike in surface water. Therefore, a less frequent sampling schedule is proposed for groundwater. The same principle applies to the sediment samples from the exact locations as the surface-water sample.

Table 8.1 Summary of the environmental monitoring programme proposed for the Project aimed at public radiation protection.

Monitoring Element	Comment	Frequency
Surface water	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Biannually
	Total Uranium and Thorium	Quarterly
Sediments	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Annually
	Total Uranium and Thorium	Biannually
Groundwater	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Once every two years
	Total Uranium and Thorium	Biannually
Radon gas	Environmental radon gas using Radon Gas Monitors (RGMs)	Quarterly for a period of 2 to 3 months
Dust fallout	Total Uranium and Thorium	Annually

The RGMs monitor radon gas for 2 to 3 months, after which they are replaced with new RGMs for the next monitoring period.

The dust-fallout samples are collected quarterly but are used to produce an annual sample for total U and Th analysis. This is because the volume of material collected in a dust bucket is insufficient for quarterly analysis.

8.4 Proposed Monitoring Points

Most proposed monitoring points coincide with the environmental pathways monitoring programme (e.g., soil, surface water, and groundwater). Considering the surface infrastructure that will be developed for the Project, the following can be noted:

- The surface water monitoring locations should align with the existing points in the public RPP. The principle to be applied is that the monitoring locations should be upstream and downstream of the Project area in potentially affected surface water streams, as well as upstream and downstream of potential discharge points.
- The sediment monitoring locations should coincide with the surface-water monitoring points, using the same principles.
- The groundwater monitoring points should coincide with the existing ones. The principle to be applied is that the monitoring locations should be upstream and downstream of the Project area, as well as upstream and downstream of specific surface facilities. The exact location will be determined by the availability of water-bearing boreholes in the specific area.
- The dust fallout monitoring locations should coincide with the monitoring points (dust buckets) proposed in Airshed (2026).
- The environmental radon monitoring locations need not coincide with specific locations. The principle is that it should be widespread across the mining rights area, aligned with the dominant wind direction at the receptor locations, and complemented by the background monitoring locations. The exact location is often determined by the availability of a secure location, which can improve the recovery rate of the RGMs.

9 Conclusions and Recommendations

9.1 General

The purpose of the radiological public safety and impact assessment was to demonstrate that members of the public living near the Project will not be exposed to ionising radiation levels exceeding the regulatory compliance criteria for public protection, and to assess the associated radiological impact as input to the ESHIA process. A systematic approach was followed, including defining the regulatory framework and the technical basis of the assessment, describing the system, defining public exposure conditions, analysing the consequences of those conditions, and conducting the radiological impact assessment.

The section is structured as follows. Section 9.2 presents general conclusions derived from the radiological impact assessment results, while Section 9.3 presents recommendations for improving radiological public safety and the impact assessment.

9.2 Conclusions

Following a systematic Source-Pathway-Receptor analysis, two public exposure conditions were derived for the area: a Residential Area Exposure Condition and a Commercial Agricultural Exposure Condition. The atmospheric pathway was explicitly included in the definition of the exposure conditions, whereas the surface water and groundwater pathways were treated through sensitivity and uncertainty analysis. It was argued that the public exposure condition is broadly representative of the human behavioural conditions near the Project. In addition, other potential exposure conditions may result in lower radiation exposure levels.

Given the pre-operational status of the Project, the radiological assessment is prospective, based on available information and reports generated as part of the ESHIA process. The results and conclusion are presented here; therefore, the conditions and parameter values assumed for the assessment are presented. These may change in future iterations as site-specific data and information become available and are used.

The following was concluded from the total effective dose assessment results:

- The most significant contributions to the atmospheric pathway are ingestion, due to high TSP deposition rates, and radon inhalation.
- The contribution from the groundwater pathway was evaluated, with the Deelkraal II TSF as the primary source. It was illustrated that the potential radiological impact is only visible over thousands of years at maximum total effective doses of less than 200 μSv.year^{-1}, indicating that it cannot be considered a contributing pathway for the Commercial Agricultural Exposure Condition during the operational phase of the Project.
- The results for the two public exposure conditions were presented as dose isopleths for the most affected age group, with more detailed exposure route-specific results at receptor locations conservatively selected to be close to the infrastructure of the Project. The results show that, for almost all selected receptor locations, the doses remain below the dose constraint for all age groups, with a maximum contribution from the atmospheric pathway of less than 250 μSv.year^{-1}. The exception is the Farm 7 receptor location, which could receive total doses of up to 280 μSv.year^{-1}, slightly above the dose constraint. Note that this applies only to the 0 to 2 year age group, with all other age groups having effective doses below 250 μSv.year^{-1}.

It can, therefore, be concluded with a reasonable level of assurance that members of the public who can associate themselves with one of the exposure conditions will not be subject to a total effective dose of more than the public dose constraint of 250 µSv.year^{-1}.

These total effective dose assessment results were used to determine the radiological impact rating during the different phases of the Project. Table 9.1 summarises the radiological impact significance rating for the operational phase, while Table 9.2 summarises the significance rating for the post-closure phase of the Project.

Table 9.1 Summary of the radiological impact significance rating for the operational phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Exhalation and dispersion of radon gas to the atmosphere during the operational phase of the Project				
Pre-Mitigation					-2.75
Nature	-1	Likely to result in a negative impact	-5.5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of radon inhalation to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	3	The impact is reversible, but at significant time and cost to reduce the radon exhalation rate from the TSF.			
Probability	2	There is a low probability that the radon inhalation dose will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-2.75		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of radon inhalation to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	3	The impact is reversible by incurring significant time and cost to reduce the radon exhalation rate from the TSF.			
Probability	1	It is improbable that the radon inhalation dose will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			
Impact	Emission and dispersion of particulate matter that contains radionuclides to the atmosphere during the operational phase of the Project				
Pre-Mitigation					-2.5
Nature	-1	Likely to result in a negative impact	-5		

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible, but at significant time and cost to reduce wind erosion from the TSF.			
Probability	2	There is a low probability that the contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact			
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}	-2.5		
Reversibility	2	The impact is reversible by incurring significant time and cost to reduce the wind erosion from the TSF.			
Probability	1	It is improbable that the contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction			
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.		1	
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			
Impact	Retreatment of the existing TSFs during the operational phase of the Project.				
Pre-Mitigation					12
Nature	1	Likely to result in a positive impact			
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter as the facility is removed from surface	6		
Magnitude	2	Low. Facilities to be removed but footprint areas to remain, which need to be rehabilitated			
Reversibility	3	The impact is reversible by incurring significant time and cost to reduce the wind erosion from the TSF			
Probability	2	There is a low probability that the impact will occur			
Post Mitigation					
Nature	1	Likely to result in a positive impact	12		

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter as the facility is removed from surface			
Magnitude	3	Moderate. Facilities to be removed but footprint areas to remain, which need to be rehabilitated			
Reversibility	3	The impact is reversible by incurring significant time and cost to reduce the wind erosion from the TSF			
Probability	3	There is a medium probability that the impact will occur			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

Table 9.2 Summary of the radiological impact significance rating for the post-closure phase of the Project.

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Impact	Implementation of the NNR-approved decommissioning plan of the Project				
Pre- and Post-Mitigation					16
Nature	1	Likely to result in a positive impact			
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The effective implementation of the decommissioning plan will have an irreversible impact that will remain after the closure.	16		
Magnitude	4	The impact on members of the public will be high and widespread			
Reversibility	5	The implementation of a good decommissioning plan is irreversible			
Probability	4	There is a low probability that the secondary pathway induced by wind erosion will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction			
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.		1	
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			
Impact	Exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of the Project				
Pre-Mitigation					-2.5
Nature	-1	Likely to result in a negative impact			
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for as long as the TSF is at the surface	-5		
Magnitude	1	Minor. The contribution of dust and radon gas inhalation, as well as the dust deposition (and the subsequent secondary pathway) to the total effective			

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
		dose, is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible by incurring significant time and cost to reduce the wind erosion from the TSF.			
Probability	2	There is a low probability that the contribution of radon inhalation, dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-2.5		
Extent	2	The extent of potential impact for the Deelkraal II TSF is limited to the site (i.e., within the development property boundary)			
Duration	5	The impact will occur for the duration of the operational phase and thereafter for as long as the TSF is at the surface.			
Magnitude	1	Minor. The contribution of dust inhalation and dust deposition (and the subsequent secondary pathway) to the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible without incurring significant time and cost to reduce the wind erosion from the TSF.			
Probability	1	It is improbable that the contribution of radon inhalation, dust inhalation and dust deposition (and the subsequent secondary pathway) will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			
Impact	Leaching and migration of radionuclides from the TSF during the post-closure phase of the Project				
Pre-Mitigation					-6
Nature	-1	Likely to result in a negative impact	-6		
Extent	3	Exposure extent beyond the mining rights area into the immediate surroundings with agricultural land use conditions in the direction of flow			
Duration	5	The impact will occur for as long as the TSF is at the surface			
Magnitude	1	Minor. The impact is expected in the immediate surroundings, and for the defined exposure conditions, the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	3	The impact is reversible only by incurring significant time and cost to reduce radionuclide migration from the TSF into the environment.			
Probability	2	There is a low probability that the contribution of radionuclides released from the TSF into the environment will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Post Mitigation					
Nature	-1	Likely to result in a negative impact	-6		
Extent	3	Exposure extent beyond the mining rights area into the immediate surroundings with agricultural land use conditions in the direction of flow			

Dimensions	Score	Motivation	Environmental Risk	Priority Factor	Final score
Duration	5	The impact will occur for as long as the TSF is at the surface			
Magnitude	1	Minor. The impact is expected in the immediate surroundings, and for the defined exposure conditions, the total effective dose is significantly lower than the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Reversibility	2	The impact is reversible only by incurring significant time and cost to reduce radionuclide migration from the TSF into the environment.			
Probability	2	There is a low probability that the contribution of radionuclides released from the TSF into the environment will be above the regulatory compliance criteria (dose constraint) of 250 µSv.year^{-1}			
Priority Factor Criteria					
Confidence	High	There is a high level of confidence in the impact prediction		1	
Cumulative Impact	1	It is unlikely that the impact will result in spatial and temporal cumulative change.			
Irreplaceable loss	1	It is unlikely that the impact will result in an irreplaceable loss of resources.			

9.3 Recommendations

The proposed radiological monitoring programme for the Project includes recommendations for monitoring surface water, groundwater, sediment, environmental radon, and dust fallout, including the frequency and type of analyses. Most proposed monitoring points coincide with the environmental pathways monitoring programme (e.g., soil, surface water, and groundwater), which is consistent with the current Public Radiation Protection Programme (PRPP). Considering the surface infrastructure that will be developed for the Project, the following was noted:

- The surface water monitoring locations should align with the existing points in the public RPP. The principle to be applied is that the monitoring locations should be upstream and downstream of the Project area in potentially affected surface water streams, as well as upstream and downstream of potential discharge points.
- The sediment monitoring locations should coincide with the surface water monitoring points, applying the same principles.
- The groundwater monitoring points should align with the existing ones. The principle to be applied is that the monitoring locations should be upstream and downstream of the Project area, as well as upstream and downstream of specific surface facilities. The exact location will be determined by the availability of water-bearing boreholes in the specific area.
- The dust fallout monitoring locations should coincide with the monitoring points (dust buckets) proposed in Airshed (2026).
- The environmental radon monitoring locations need not coincide with specific locations. The principle is to apply it across the mining rights area, in the dominant wind direction relative to the receptors, and to complement it with monitoring locations in the background. The exact location is often determined by the availability of a secure location, which can improve the recovery rate of RGMs.

10 References

Airshed (2022), Air Quality Specialist Study for the Harmony Kusasalethu Operations near Carletonville, *Report No: 21ASC02*, Airshed Planning Professionals (Pty) Ltd, Midrand.

Airshed (2026), Air Quality Impact Assessment Report for the Harmony West Wits Reclamation and Deposition Project.

AquiSim (2023), 2022 Kusasalethu Radiological Public Safety Assessment.

AquiSim (2024), Conceptual and Mathematical Model Development: Mining and Mineral Processing Facilities, *Report No. ASC-0001A*, AquiSim Consulting (Pty) Ltd, Centurion, South Africa.

ARP Consulting (2026), Conceptual and Mathematical Model Development: Mining and Mineral Processing Facilities, *Report No. ARP-1001A*, AquiSim Consulting (Pty) Ltd, Great Brak River, South Africa.

Botha, J. C. (2005), The Assessment of Potential Radiation Hazards to Members of the Public from Harmony Elandsrand and Deelkraal Operations - CoR No: 28, Harmony Gold Mining Company Limited

Chambers, D. B., L. M. Lowe, and D. G. Feasby (2012), Radiological Aspects of Naturally Occurring Radioactive Material (NORM) in the Processing and Production of Rare Earth Element Concentrates, paper presented at Rare Earths 2012 51st Annual Conference of Metallurgists of CIM (COM 2012), Niagara, ON, Canada.

DME (2005), Radioactive Waste Management Policy and Strategy for the Republic of South Africa, Department of Mineral and Energy, Pretoria.

EIMS (2026), Scoping Report – Harmony West Wits Reclamation and Deposition Project: (GP) 30/5/1/1/2 (07) MR.

Equispectives (2026), Social Impact Assessment: Proposed West Wits Reclamation and Deposition Project.

Hydrologic Consulting (2026), Hydrological Assessment for the Proposed Harmony West Wits Reclamation and Deposition Project.

IAEA (1994), Classification of Radioactive Waste, *Safety Series No. 111-G-1.1*, International Atomic Energy Agency, Vienna, Austria.

IAEA (1995), The Principles of Radioactive Waste Management, *International Atomic Energy Agency Safety Series Report No. 111-F*, International Atomic Energy Agency, Vienna.

IAEA (1997), Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories, *IAEA TECDOC-767*, International Atomic Energy Agency, Vienna.

IAEA (2001), Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Report Series No.19, International Atomic Energy Agency, Vienna.

IAEA (2002), Monitoring and Surveillance of Residue from the Mining and Milling of Uranium and Thorium, Safety Report Series No.27, International Atomic Energy Agency, Vienna.

IAEA (2004a), Radiation, People and the Environment, *IAEA/PI/A.75/ 04-00391*, International Atomic Energy Agency, Vienna.

IAEA (2004b), Safety Assessment Methodologies for Near Surface Disposal Facilities. Results of a Co-ordinated Research Project. Volume I: Review and Enhancement of Safety Assessment Approaches and Tools, *IAEA-ISAM*, International Atomic Energy Agency, Vienna.

IAEA (2004c), Safety Assessment Methodologies for Near Surface Disposal Facilities Results of a Coordinated Research Project, Volume I: Review and Enhancement of Safety Assessment Approaches and Tools, IAEA-ISAM, International Atomic Energy Agency, Vienna.

IAEA (2006), Fundamental Safety Principles, *Safety Standard Series No. SF-1*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2007), IAEA Safety Glossary. Terminology used in Nuclear Safety and Radiation Protection, *2007 Edition*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2009a), Safety Assessments for Facilities and Activities, *Safety Standard Series No. GSR Part 4*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2009b), Classification of Radioactive Waste, *Safety Standard Series No. GSG-1*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2011), Disposal of Radioactive Waste *Safety Standard Series No. SSR-5*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2012), The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, *Specific Safety Guide No. SSG-23*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2014), Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards: General Safety Requirements, *IAEA Safety Standards Series No. GSR Part 3*, International Atomic Energy Agency, Vienna, Austria.

IAEA (2018), IAEA Safety Glossary https://kos.iaea.org/iaea-safety-glossary.html, edited, International Atomic Energy Agency, Vienna, Austria.

ICRP (1991), 1990 Recommendations of the International Commission on Radiological Protection. Annals of the ICRP 21 (1-3), *ICRP Publication 60*, International Commission on Radiological Protection.

ICRP (2000), *Publication 82. Protection of the Public in Situations of Prolonged Radiation Exposure. The Application of the Commission's System of Radiological Protection to Controllable Radiation Exposure Due to Natural Sources and Long-Lived Radioactive Residues. Annals of the ICRP*, First ed., Elsevier Science Ltd, Oxford.

ICRP (2006), Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public, *ICRP Publication 101a*, International Commission on Radiological Protection (ICRP).

ICRP (2007), The 2007 Recommendations of the International Commission on Radiological Protection, *ICRP Publication 103. Ann. ICRP*, *Volume 37*(Issue 2-4).

ICRP (2008), Publication 103, Recommendations of the ICRP - Annals of the International Commission on Radiological Protection (ICRP), Published for the ICRP by Elsevier Inc, Vienna.

ICRP (2009a), Publication 108. Environmental Protection: The Concept and Use of Reference Animals and Plants.: Annals of the International Commission on Radiological Protection (ICRP) Vienna.

ICRP (2009b), Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations, *ICRP Publication 109. Ann. ICRP 39 (1).* Vienna.

Kathren, R. L. (1998), NORM Sources and Their Origins, *Applied Radiation and Isotopes*, *49*(3), 149–168.

Klaassen, C. D. (2001), *Casarett and Doull's Toxicology, The Basic Science of Poisons*, 6th ed., McGraw-Hill, New York (NY).

Kozak, M. W., and W. Zhou (1998), The Use of Interaction Matrices to Improve Assessment Transparency, TR-108732, EPRI, Palo Alto.

Marsh, J. W., J. D. Harrison, and D. Laurier (2010), Dose Conversion Factors for radon:Recent Developments, *Health Physics*, *October 99*(4), pp. 511 – 516.

Martin, J. E. (2006a), *Physics for Radiation Protection: A Handbook. Second Edition, Completely Revised and Enlarged*, Wiley-VCH, Weinheim.

Martin, J. E. (2006b), *Physics for Radiation Protection: A Handbook*, Wiley-VCH, Weinheim.

MvB Consulting (2026), Hydrogeological Assessment for the Proposed Gold Reclamation from the Khusasaleka and Deelkraal Tailings Facilities and the Redeposition on a New TSF, *MVB215/26/B072*.

NEA (1997), Lessons learnt from ten performance assessment studies. Report of the NEA working group on integrated performance assessment of deep repositories, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, Paris.

NNR (2013), Safety Assessment of Radiation Hazards to Members of the Public from NORM Activities, *Regulatory Guide RG-002 (Rev 0)*, National Nuclear Regulator, Centurion, South Africa.

NRC (2003), *Conceptual Models of Flow and Transport in the Fractured Vadose Zone*, National Academy Press, Washington, D.C.

Oreskes, N., K. Shrader-Frechette, and K. Belitz (1994), Verification, validation, and confirmation of numerical models in the Earth sciences, *Science & Global Security*, *263*, 641–646.

Parc Scientific (2006), Summary of radon exhalation rate surveys on slimes dams, sand dumps and waste rock piles in the South African gold mining industry using the PARC diffusion tube method., Parc Scientific (Pty) Ltd, Ifafi, South Africa.

Savage, D. (1995), *The Scientific and Regulatory Basis for the Geological Disposal of Radioactive Waste*, John Wiley & Sons.

Till, J. E., and H. A. Grogan (2008), *Radiological Risk Assessment and Environmental Analysis*, Oxford University Press, USA.

UNEP (2016), *Radiation Effects and Sources*, United Nations Environment Programme.

Yu, C., C. Loureiro, J.-J. Cheng, L. G. Jones, Y. Y. Wang, Y. P. Chia, and E. Faillace (1993), Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil, *Report ANL/EAIS-8*, Argonne National Laboratory.

Appendix A:
Radionuclide and Element-Dependent Data

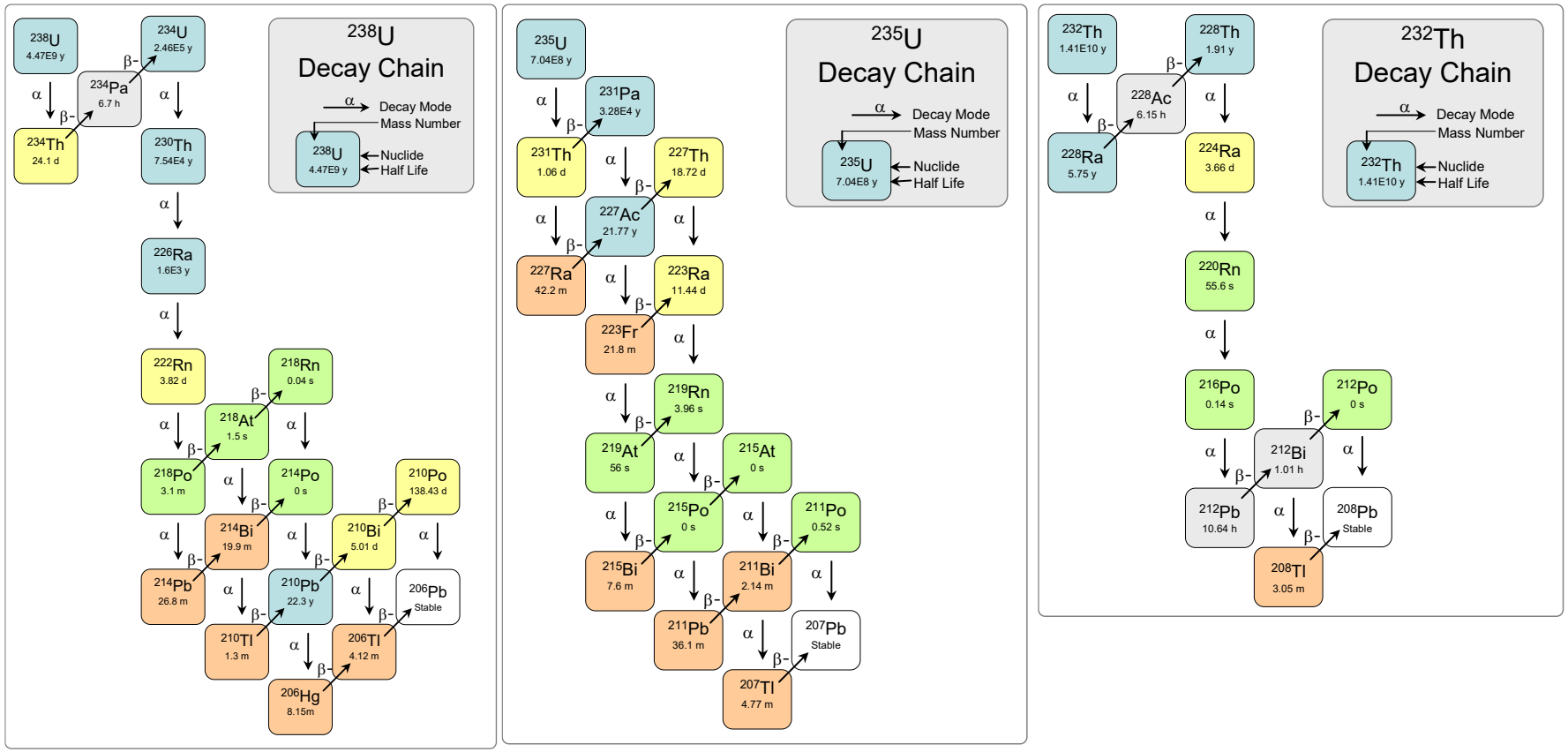


Figure A 1 **Schematic illustrations of the U-238, U-235, and Th-232 decay chains.**

Table A 1 Radiological properties for the Uranium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Units	Decay Constant	Half-Life (years)	Decay Constant (years)	Atomic Mass	Specific Activity ($Bg.kg^{-1}$)
Uranium	U-238	α	4.468E+09	y	1.551359E-10	4.468000E+09	1.551359E-10	238.05	1.243803E+07
Thorium	Th-234	β	2.410E+01	d	2.876129E-02	6.598220E-02	1.050506E+01	234.04	8.566645E+17
Protactinium	Pa-234m	β	1.170E+00	m	5.924335E-01	2.224504E-06	3.115963E+05	234.04	2.541002E+22
Uranium	U-234	α	2.445E+05	y	2.834958E-06	2.445000E+05	2.834958E-06	234.04	2.311871E+11
Thorium	Th-230	α	7.700E+04	y	9.001911E-06	7.700000E+04	9.001911E-06	230.03	7.468842E+11
Radium	Ra-226	α	1.600E+03	y	4.332170E-04	1.600000E+03	4.332170E-04	226.03	3.658113E+13
Radon	Rn-222	α	3.824E+00	d	1.812860E-01	1.046817E-02	6.621473E+01	222.02	5.692148E+18
Polonium	Po-218	α	3.050E+00	m	2.272614E-01	5.798920E-06	1.195304E+05	218.01	1.046437E+22
Lead	Pb-214	β	2.680E+01	m	2.586370E-02	5.095445E-05	1.360327E+04	214.00	1.213218E+21
Bismuth	Bi-214	β	1.990E+01	m	3.483152E-02	3.783558E-05	1.831998E+04	214.00	1.633890E+21
Polonium	Po-214	α	1.643E+02	us	4.218790E-03	5.206353E-12	1.331349E+11	214.00	1.187399E+28
Lead	Pb-210	β	2.230E+01	y	3.108283E-02	2.230000E+01	3.108283E-02	209.98	2.825159E+15
Bismuth	Bi-210	β	5.012E+00	d	1.382975E-01	1.372211E-02	5.051317E+01	209.98	4.591209E+18
Polonium	Po-210	α	1.384E+02	d	5.009013E-03	3.788638E-01	1.829542E+00	209.98	1.662905E+17

Table A 2 Radiological properties for the Actinium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Units	Decay Constant	Half-Life (years)	Decay Constant (years)	Atomic Mass	Specific Activity ($Bg.kg^{-1}$)
Uranium	U-235	α	7.038E+08	y	9.848639E-10	7.038000E+08	9.848639E-10	235.04	7.997165E+07
Thorium	Th-231	β	2.552E+01	h	2.716094E-02	2.911248E-03	2.380928E+02	231.04	1.966867E+19
Protactinium	Pa-231	α	3.276E+04	y	2.115834E-05	3.276000E+04	2.115834E-05	231.04	1.747878E+12
Actinium	Ac-227	β	2.177E+01	y	3.183517E-02	2.177300E+01	3.183517E-02	227.03	2.676315E+15
Thorium	Th-227	α	1.872E+01	d	3.703105E-02	5.124709E-02	1.352559E+01	227.03	1.137068E+18
Radium	Ra-223	α	1.143E+01	d	6.062158E-02	3.130459E-02	2.214203E+01	223.02	1.894897E+18
Radon	Rn-219	α	3.960E+00	s	1.750372E-01	1.254848E-07	5.523753E+06	219.01	4.813713E+23
Polonium	Po-215	α	1.780E-03	s	3.894085E+02	5.640480E-11	1.228880E+10	215.00	1.090890E+27
Lead	Pb-211	β	3.610E+01	m	1.920075E-02	6.863640E-05	1.009883E+04	210.99	9.135254E+20
Bismuth	Bi-211	α	2.140E+00	m	3.239006E-01	4.068750E-06	1.703587E+05	210.99	1.541051E+22
Thallium	Tl-207	β	4.770E+00	m	1.453139E-01	9.069131E-06	7.642929E+04	206.98	7.047673E+21

Table A 3 Radiological properties for the Thorium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Units	Decay Constant	Half-Life (years)	Decay Constant (years)	Atomic Mass	Specific Activity ($Bg.kg^{-1}$)
Thorium	Th-232	α	1.405E+10	y	4.933432E-11	1.405000E+10	4.933432E-11	232.04	4.057876E+06
Radium	Ra-228	β	5.750E+00	y	1.205473E-01	5.750000E+00	1.205473E-01	228.03	1.008957E+16
Actinium	Ac-228	α	6.130E+00	h	1.130746E-01	6.992927E-04	9.912118E+02	228.03	8.296243E+19
Radium	Ra-224	α	3.660E+00	d	1.893845E-01	1.002053E-02	6.917268E+01	224.02	5.893270E+18
Radon	Rn-220	α	5.560E+01	s	1.246668E-02	1.761858E-06	3.934184E+05	220.01	3.412859E+22
Polonium	Po-216	α	1.500E-01	s	4.620981E+00	4.753213E-09	1.458271E+08	216.00	1.288515E+25
Lead	Pb-212	β	1.064E+01	h	6.514541E-02	1.213781E-03	5.710647E+02	211.99	5.141324E+19
Bismuth	Bi-212	β	6.055E+01	m	1.144752E-02	1.151228E-04	6.020936E+03	211.99	5.420695E+20
Polonium	Po-212	α	3.050E-01	us	2.272614E+00	9.664867E-15	7.171823E+13	211.99	6.456921E+30