

in the flow tube originating from the source, while the other part of the borehole intersects uncontaminated "background" groundwater. Figure 4.7 is a simplified representation of the borehole abstraction module and the most important parameters.

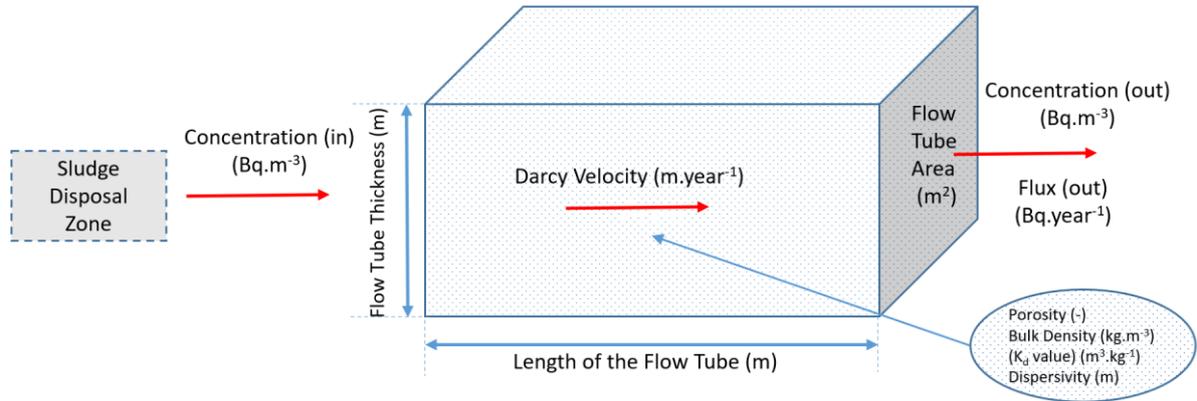


Figure 4.6 Conceptual representation and associated parameter values for the aquifer (saturated zone) model.

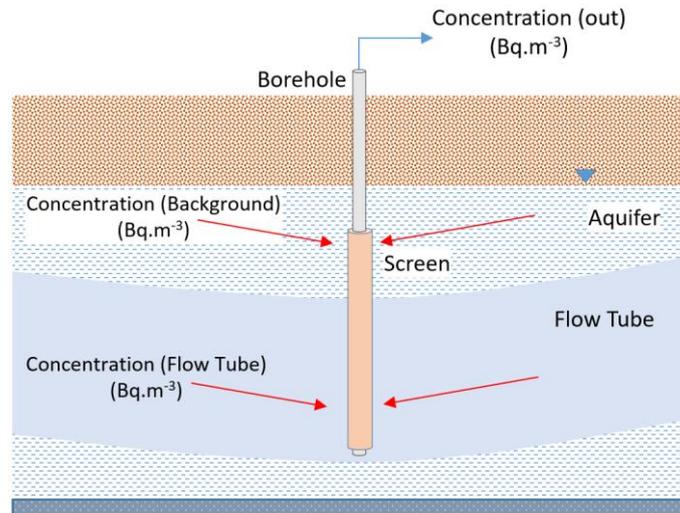


Figure 4.7 Conceptual representation and associated parameter values for the borehole abstraction model.

The concentration of the water abstracted from the borehole is simplistically taken as the sum of the flow tube concentration (Bq.m^{-3}) multiplied by the fraction of the borehole intersecting the plume, and the background concentration (Bq.m^{-3}) multiplied by the fraction intersecting the uncontaminated water. The resulting radionuclide concentration in groundwater extracted from the borehole ($C_{\text{Water, Bh, out}}$, in Bq.m^{-3}) is defined as follows:

Equation 6

$$C_{\text{Water, Bh, out}} = f_{\text{Bh}} \cdot C_{\text{Water, FT, in}} + (1 - f_{\text{Bh}}) \cdot C_{\text{Water, Bg, in}}$$

where f_{Bh} is the borehole fraction intersecting contaminated groundwater originating from the contaminated site, $C_{\text{Water, FT, in}}$ is the radionuclide concentration flowing in from the flow tube into the borehole (Bq.m^{-3}) and $C_{\text{Water, Bg, in}}$ is the radionuclide concentration in background groundwater in the area flowing into the borehole (Bq.m^{-3}). As a conservative assumption, it can be assumed that the whole screen intersects the contaminant plume (i.e., f_{Bh} equals 1). Note that the conceptual representation presented above is conservative. Under site-specific conditions, abstracted groundwater from a borehole will draw water from uncontaminated areas, and the contaminated water will consequently be diluted further.

4.3.6 Parameter Values

Table 3.4 lists the available full spectrum analysis results of two ERB sludge samples, one from 2016 and one more recent sample from 2024. Table 4.4 lists the radionuclide specific activity concentrations derived for the analysis. The secular equilibrium assumptions introduced in Section 2.3.4.3 were applied to those radionuclides for which analysis results were not available in Table 3.4.

Table 4.4 The radionuclide specific activity concentrations for ERB sludge samples and their average, used for the System Level model to evaluate the radiological impact on members of the public.

Radionuclide	2016 Sample	2024 Sample	Average
	Activity Concentration (Bq.kg ⁻¹)		
U-238	503.0	178.0	340.5
U-234	507.0	179.0	343.0
Th-230	507.0	179.0	343.0
Ra-226	538.0	985.0	761.5
Pb-210	538.0	985.0	761.5
Po-210	538.0	985.0	761.5
U-235	23.1	8.2	15.6
Pa-231	23.1	8.2	15.6
Ac-227	23.1	8.2	15.6
Th-232	76.0	3.4	39.7
Ra-228	76.0	118.0	97.0

Note: Values in red were assumed to be in secular equilibrium with the parent radionuclide. Values in blue were taken to be in equilibrium with the daughter radionuclide.

Section 3.7.4 presents the mass source term after 100 years of sludge disposal. It was estimated that after 100 years of sludge deposition, the total volume of solids is in the order of 6,254,345 m³, covering an area of 1001 ha. For the radiological impact evaluation, a total thickness of 1 m was assumed over an area of 1000 ha, with a length of about 1,000 m in the direction of flow and a width of 10,000 m perpendicular to the direction of flow. The distance of the flow path from the disposal zone to a water abstraction borehole was taken to be 17 km (17,000 m), with a 1 m thickness. For transport in the Wits Quartzite (Deep Confinement Zone), a thickness of 1 m was also assumed.

Table 4.5 lists parameter values for the key geological units abstracted from the Process Level model for the ERB sludge disposal operations. Parameter values for the Main Reef in the sludge disposal zone were reduced to account for the change in properties due to the presence of the sludge that will reduce the porosity and the Darcy flux.

Table 4.5 Summary of parameter values abstracted from the Process Level model for the ERB sludge disposal operations (Artesium, 2024b).

Parameter	Unit	Main Reef (Sludge Disposal Zone)	Main Reef (Grootvlei Sub-basin)	Wits Quartzite (Deep Confinement Zone)	
Porosity	-	1.00E-01	7.00E-01	1.00E-02	
Hydraulic Conductivity	Horizontal	m.day ⁻¹	1.00E+01	1.00E+02	3.45E-01
	Vertical		1.00E+01	1.00E+02	3.45E-01
Hydraulic Head	Horizontal	-	2.65E-04	2.65E-04	2.65E-04
	Vertical		2.65E-08	2.65E-08	3.21E-07
Darcy Velocity	Horizontal	m.day ⁻¹	2.65E-03	2.65E-02	9.37E-05
	Vertical		2.65E-07	2.65E-06	1.14E-07

The most sensitive parameters in the 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 disposed sludge.

This is very conservative, assuming little absorption to retard the migration of radionuclides 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 for the analysis presented here is to use a conservative range of K_d values from the literature for illustrative purposes. Table 4.6 lists soil distribution coefficients for selected radionuclides published in RG-002 (NNR, 2013a), as well as the range of values from the literature for different soil types as published by the Argonne National Laboratory (Yu *et al.*, 1993). The comparison shows that the values of the distribution coefficients found in the literature can vary significantly.

Table 4.6 Distribution coefficients from literature for the elements of concern, as well as the K_d values in the analysis for illustrative purposes (NNR, 2013a; 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

4.3.7 Potential Radiological Impact

4.3.7.1 General

Due to the inherent complexities of the ERB sludge disposal operations, uncertainties exist within both the conceptual model and parameter values used in the System Level model. Consequently, a series of simulations were conducted to address these uncertainties and to demonstrate the sensitivity of the model to variations in its conceptual framework and parameter inputs.

4.3.7.2 Base Case

The base case analysis assumed the 2024 sample in Table 4.4 as the initial activity concentrations for the sludge disposed of in the Main Reef, with the properties of the Main Reef (Sludge Disposal Zone) and Main Reef (Grootvlei Sub-basin) as indicated in Table 4.5.

Figure 4.8 presents the resulting nuclide-specific activity concentrations in the groundwater abstracted from the borehole, which shows that the initial peak concentration is only visible after 80,000 years (the Th-232 decay chain only becomes visible after 700,000 years). If one assumes the RG-002 (NNR, 2013a) water ingestion rates for the different age groups listed in Table 4.3, then the groundwater activity concentrations in Figure 4.8 translate to water ingestion doses shown in Figure 4.9. It illustrates that for the assumed conditions, the maximum potential water ingestion dose at a borehole located 17 km from the disposal zone is only at 100,000 years, and potentially at doses between 300 and 700 $\mu Sv.year^{-1}$ for the different age groups.

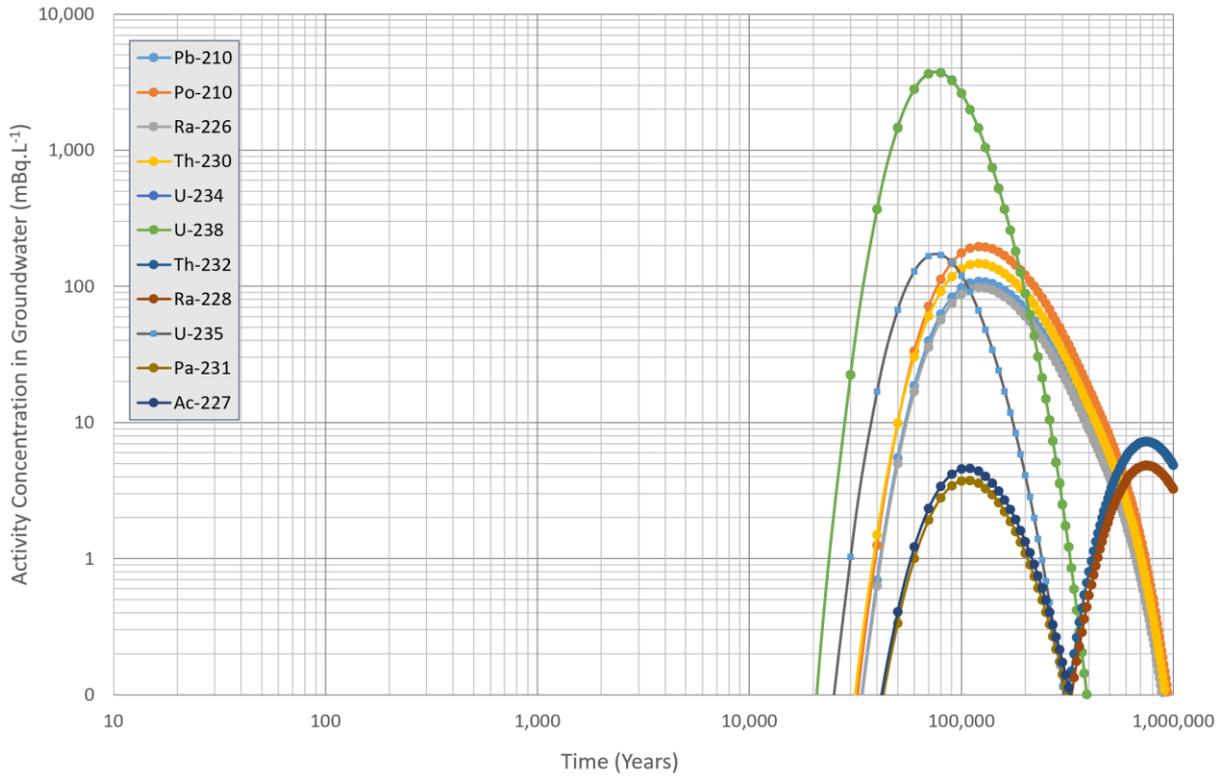


Figure 4.8 The simulated activity concentration in groundwater abstracted from a borehole 17 km from the sludge disposal zone.

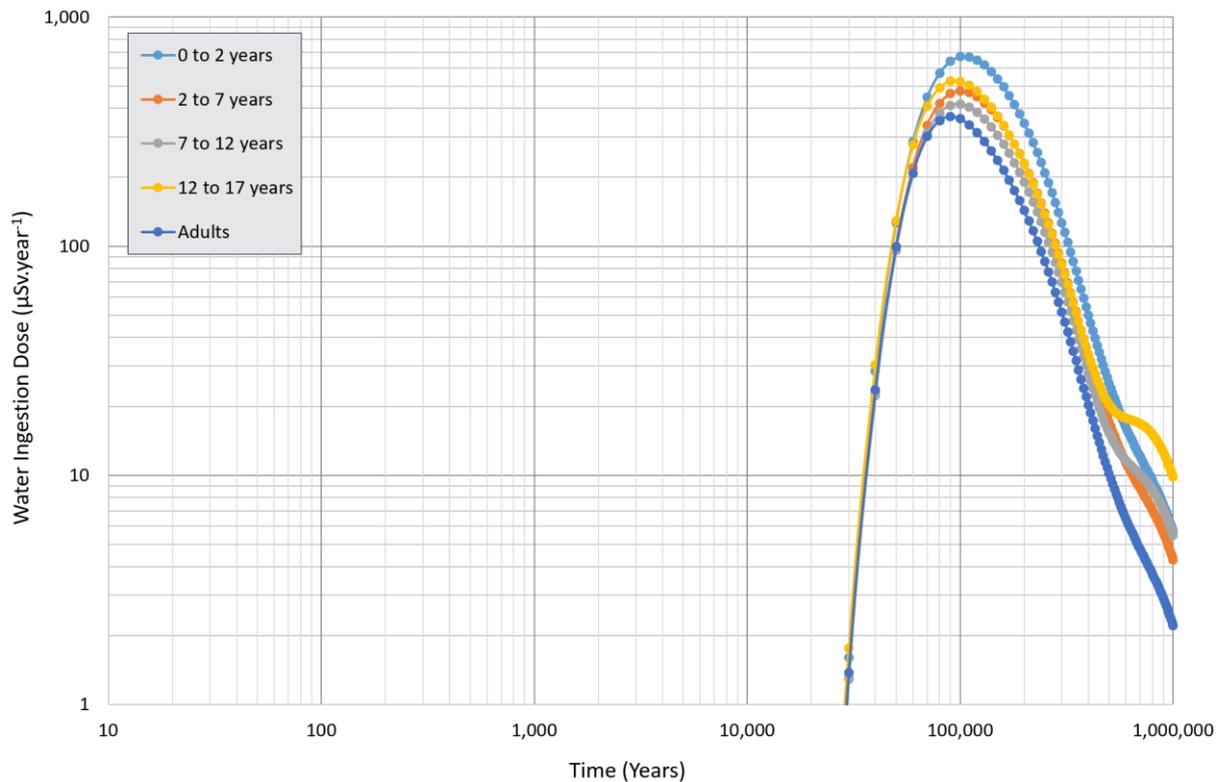


Figure 4.9 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, using the activity concentrations in Figure 4.8.

4.3.7.3 Variation in Activity Concentration

The results presented in Section 4.3.7.2 assumed the 2024 sample in Table 4.4 as the initial activity concentrations for the sludge disposed of in the Main Reef. Figure 4.10 and Figure 4.11 present the potential water ingestion doses using the 2016 and average sludge sample analysis results in Table 4.4 as the initial activity concentrations for the disposal zone. A comparison with Figure 4.9 shows that the time of maximum is the same, as expected, but that the peak doses for the different age groups are noticeably higher. This could be attributed to the higher U and Th isotope activity concentrations associated with the 2016 sample, which also influenced the average values.

4.3.7.4 Variation in K_d -values

The base case analysis assumed a conservative set of K_d -values for the different isotopes, as listed in Table 4.6. Lower K_d -values mean less adsorption, and the radionuclides will migrate faster along the Main Reef. However, it also means that radionuclides will be released faster from the disposal zone (see Equation ??). Figure 4.12 and Figure 4.13 present the potential water ingestion doses using K_d -values that are an order lower than those listed in Table 4.6 for the Base Case, and the RG-002 K_d -values listed in Table 4.6. The sensitivity of the K_d -values is clearly illustrated in comparison with Figure 4.9. The lower K_d -values in Figure 4.12 show that the plume will migrate faster through the Main Reef, reaching the first peak dose after 10,000 years at the borehole 17 km from the disposal zone but at higher water ingestion doses. The higher K_d -values in Figure 4.13 show that the plume will migrate slower through the Main Reef, reaching the first peak dose after 850,000 years at the borehole 17 km from the disposal zone but at significantly lower water ingestion doses.

4.3.7.5 Migration Through the Wits Quartzite (Deep Confinement Zone)

The Base Case assume that the plume migrates through the more permeable Main Reef. However, radionuclides may also migrate through the Wits Quartzite (Deep Confinement Zone), with parameter values as listed in Table 4.5. However, the potential water ingestion doses for migration through the quartzites are insignificant and do not reach the borehole 17 km away from the disposal zone. For illustrative purposes, the potential water ingestion doses at a point 1 km (1,000 m) from the disposal zone are presented in Figure 4.14, which shows doses in the order of $100 \mu\text{Sv}\cdot\text{year}^{-1}$ at about 900,000 years.

4.3.7.6 Variation in Darcy Flux and Porosity in the Disposal Zone

The Base Case assume that the Darcy velocity through the sludge disposal zone is an order lower than in the Main Reef. The porosity was also reduced accordingly. Figure 4.15 and Figure 4.16 present the potential water ingestion doses assuming an order higher and order lower Darcy flux through the disposal zone than those listed in Table 4.5, respectively. The porosity was adjusted to 0.7 and 0.05, respectively. Figure 4.15 shows that higher fluxes through the disposal zone will reduce the source terms release rate significantly, resulting in much lower water ingestion doses. Figure 4.16, on the other hand, shows that lower fluxes through the disposal zone will retain the radionuclides, resulting in much slower source terms release rates. This will result in higher doses at later times.

4.3.7.7 Additional Contribution from the Untreated AMD Water

The Base Case assume that the only contribution to the water ingestion dose is from the water leaching from the disposal zone. However, the untreated AMD water is likely present in the basin and that water abstracted from the basin includes AMD water. Figure 4.17 presents the potential water ingestion doses, assuming an additional contribution from the untreated AMD water sample listed in Table 4.1. It shows a marginal increase in the water ingestion dose in comparison with Figure 4.9 but with a constant contribution after the plume itself dissipated.

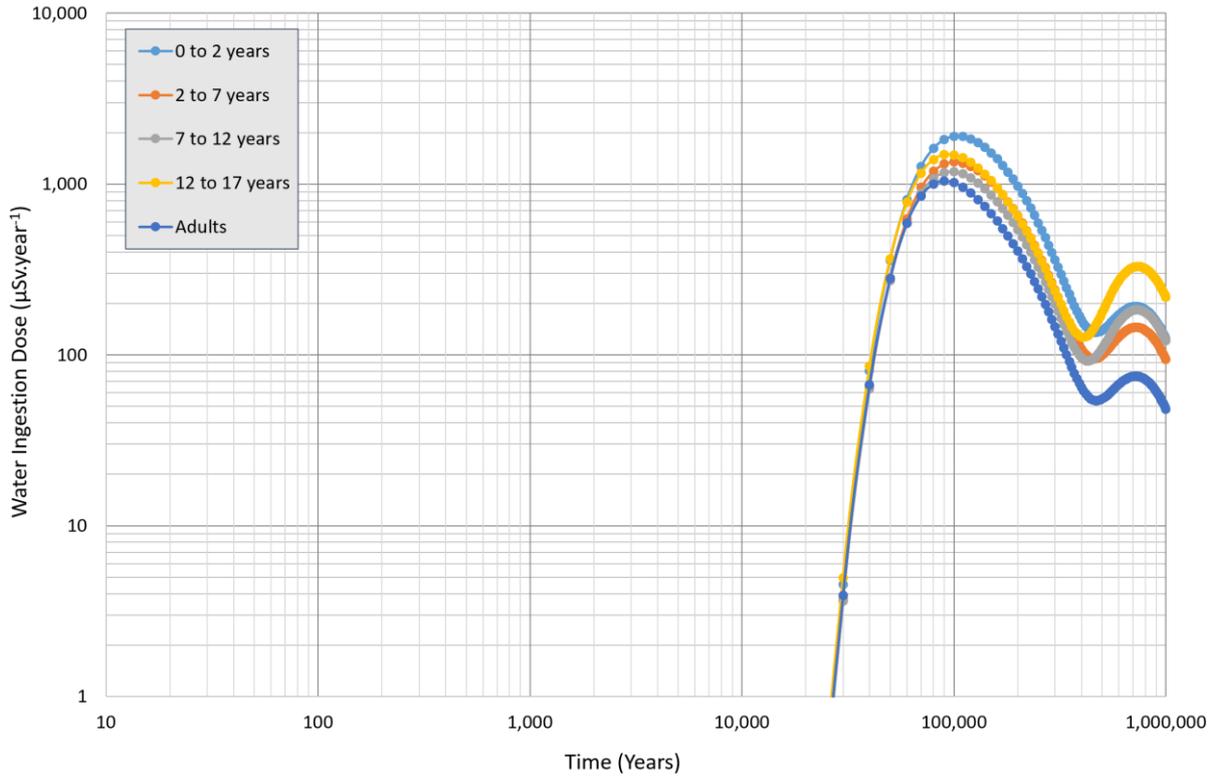


Figure 4.10 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, using the 2016 sludge sample in Table 4.4 as the initial activity concentrations.

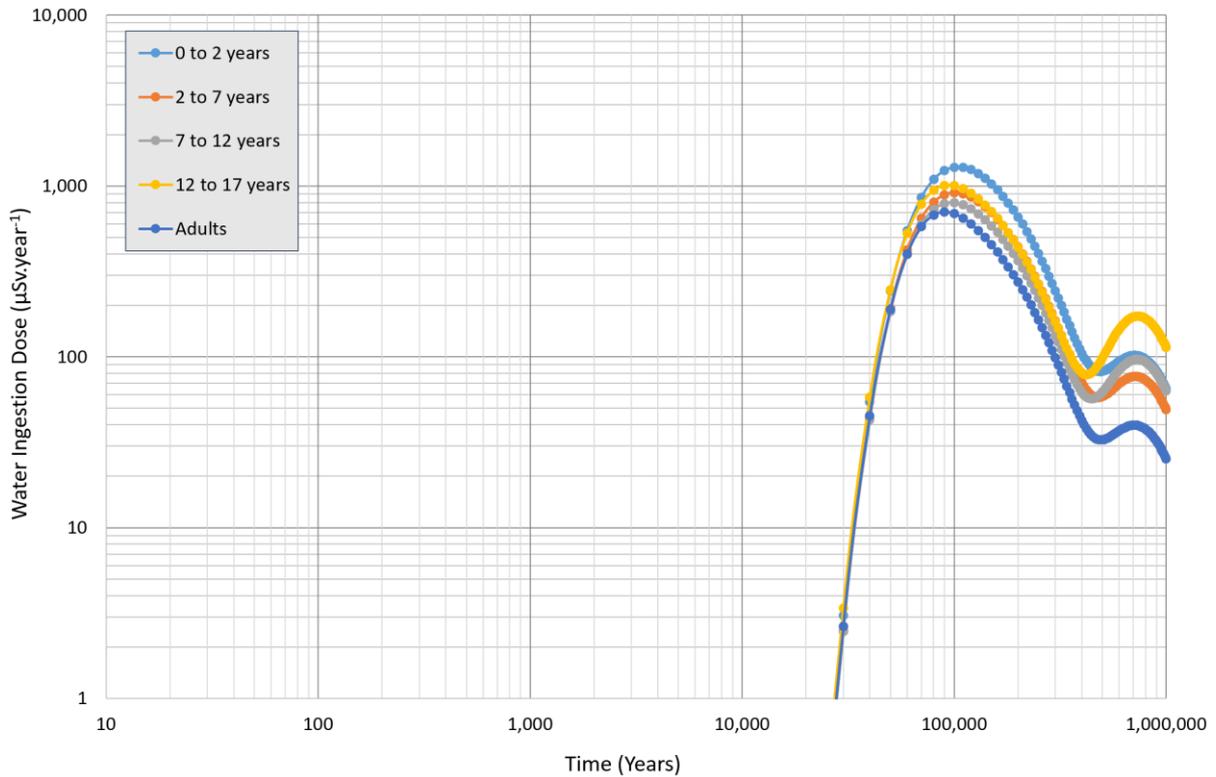


Figure 4.11 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, using the average values in Table 4.4 as the initial activity concentrations.

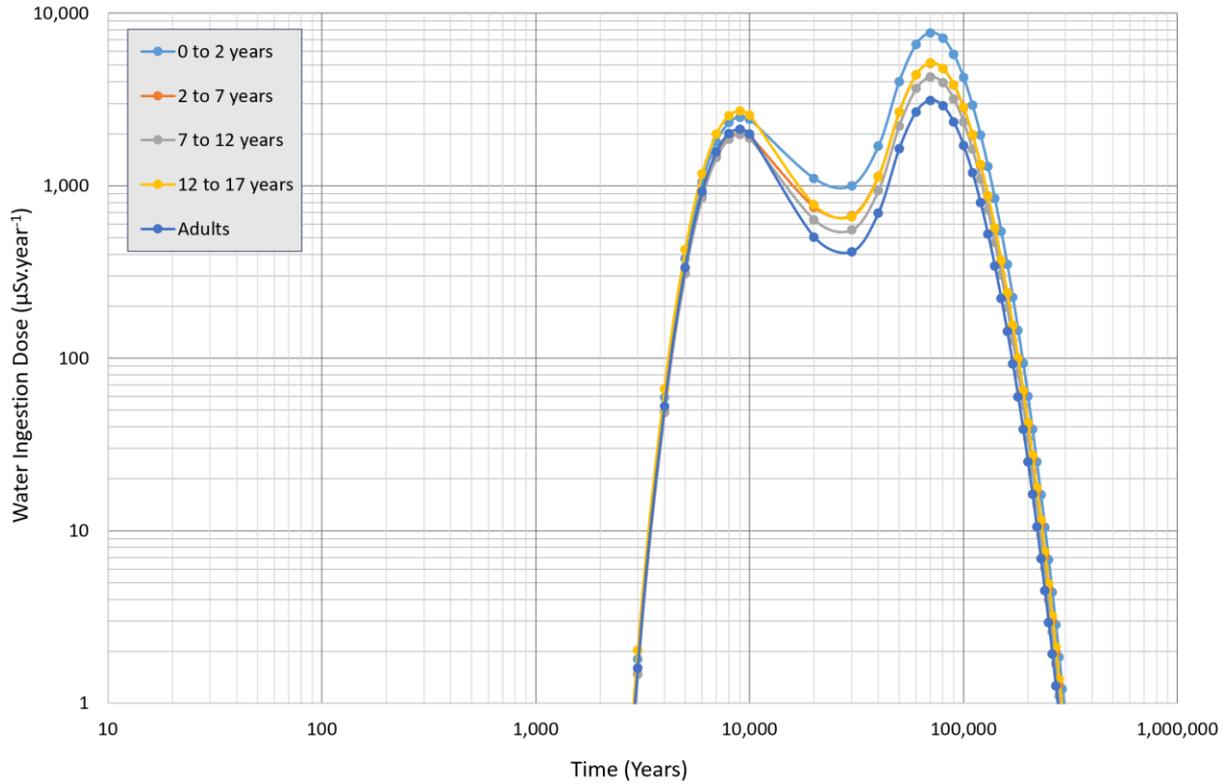


Figure 4.12 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, using K_d -values that are an order lower than listed in Table 4.6 for the Base Case.

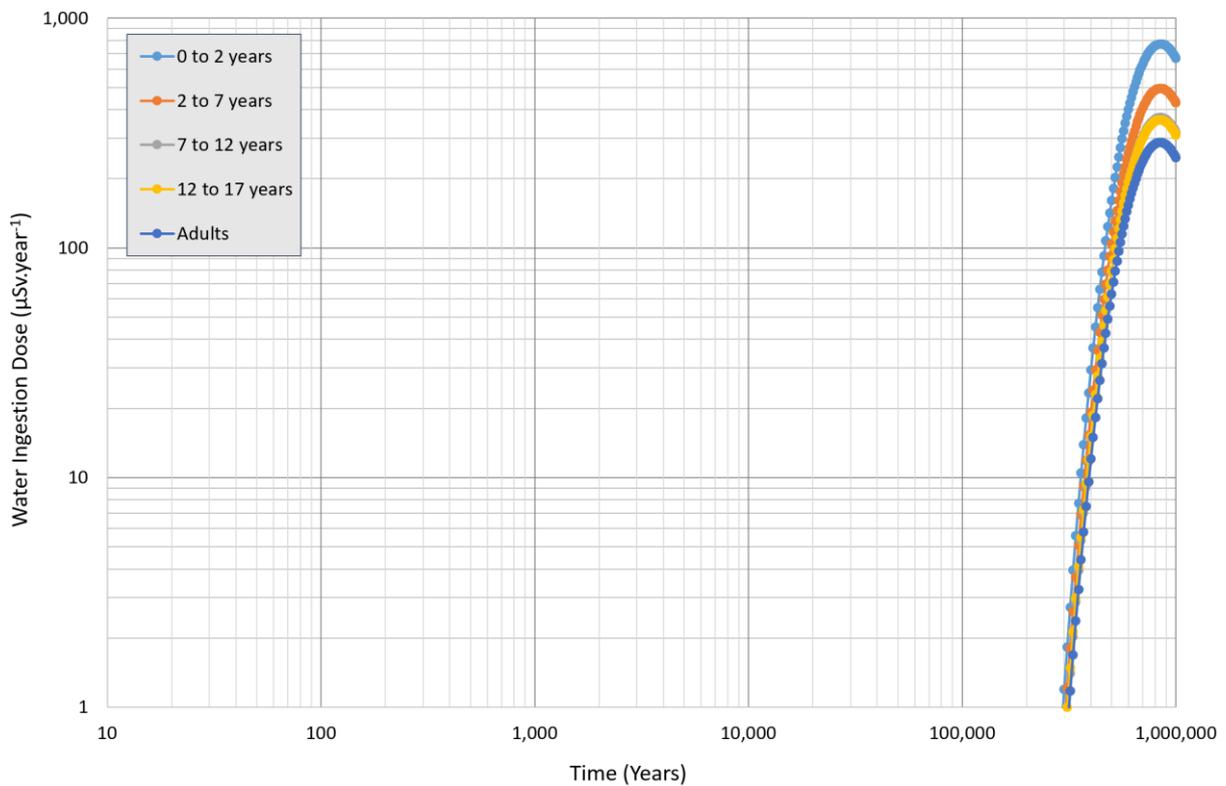


Figure 4.13 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, using the RG-002 K_d -values listed in Table 4.6.

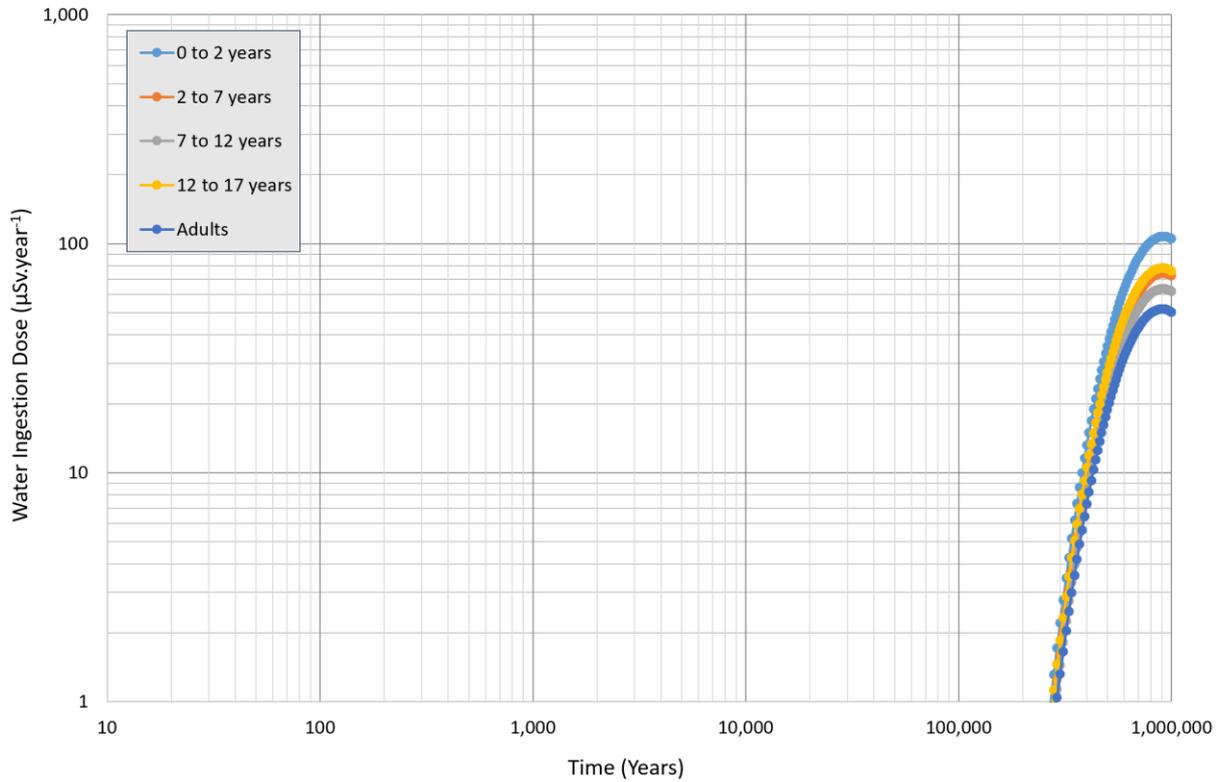


Figure 4.14 The simulated water ingestion dose to the different age groups 1 km from the sludge disposal zone, assuming migration is the Wits Quartzite (Deep Confinement Zone).

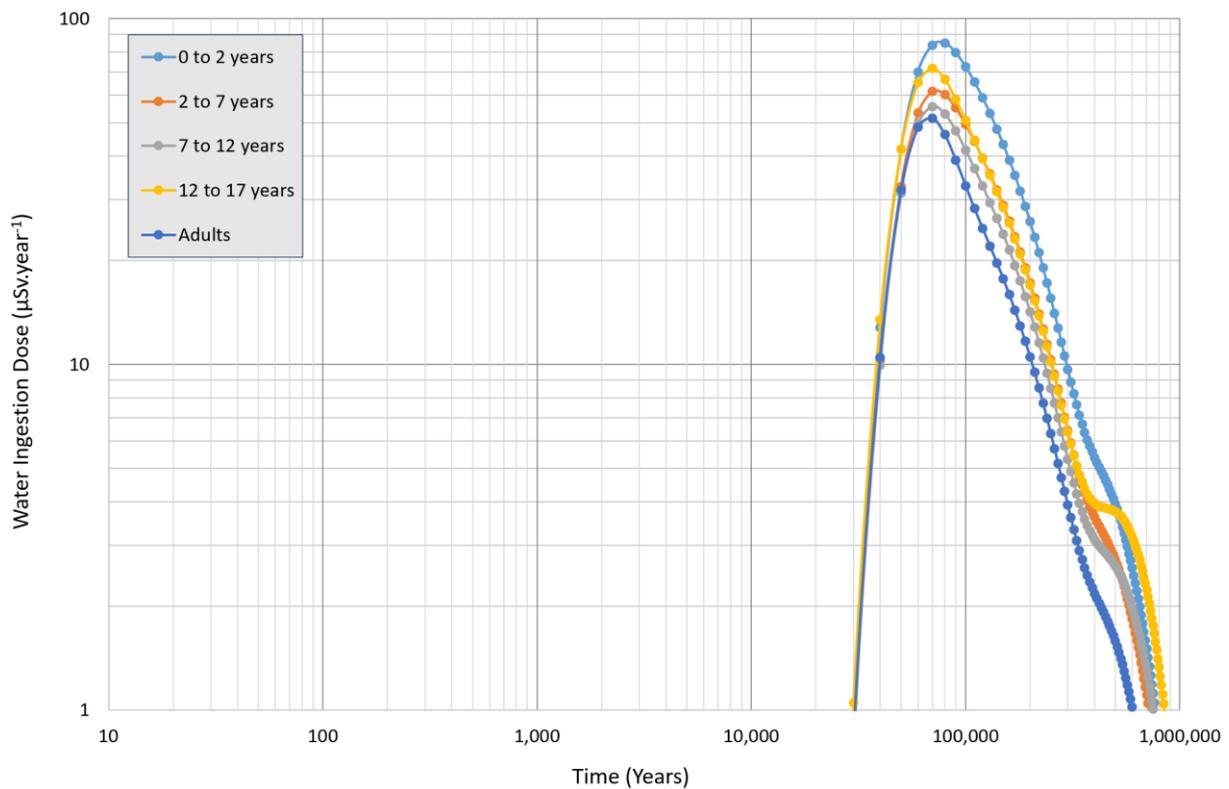


Figure 4.15 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, assuming an order high Darcy flux through the sludge disposal zone.

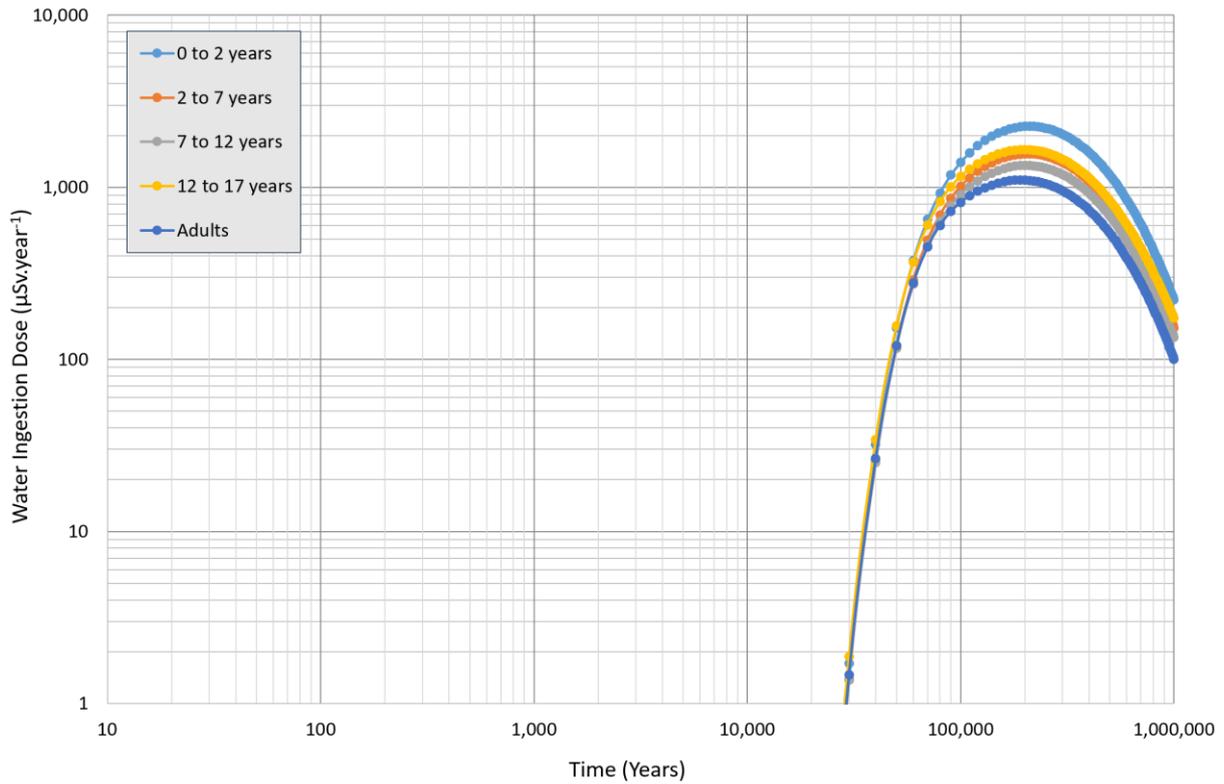


Figure 4.16 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, assuming an order lower Darcy flux through the sludge disposal zone.

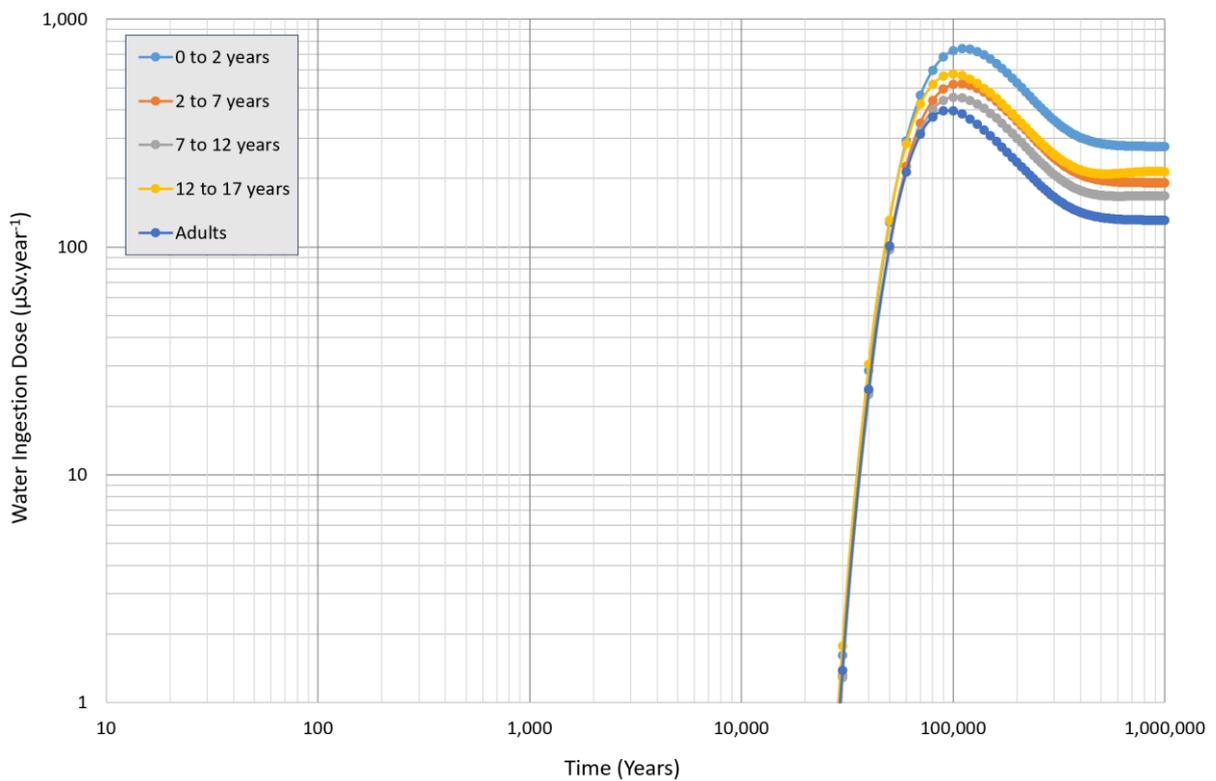


Figure 4.17 The simulated water ingestion dose to the different age groups 17 km from the sludge disposal zone, assuming an additional contribution from the untreated AMD water sample listed in Table 4.1.

4.3.8 Discussion of the Results

The potential radiological impact on the public from the sludge disposal operations was assessed through a series of simulations that explored alternative conceptual models and varied parameter values. This evaluation relied on water ingestion doses, which were compared against the established public dose limit criterion. For this purpose, it was assumed that water is abstracted from the centre of the plume without any dilution from uncontaminated water. Notably, if just 20% of the extracted water were uncontaminated, the calculated doses would be reduced by 20%. In addition, the water ingestion doses were calculated assuming that the abstracted water was the only source of water. For this purpose, the RG-002 suggested ingestion rates were used. Again, if the ingestion rates are reduced by 20%, the calculated doses would be reduced by 20%.

It is important to note that using water ingestion doses as a benchmark is a very conservative approach, given that the quality of untreated water is unsuitable for human consumption—not only from a radiological health perspective but even more so from a macro-chemical standpoint.

The radiological impact assessment assumed that the disposal operations were performed for 100 years, after which the Grootvlei Sub-basin will be filled to only 2% of its disposal capacity. Under these conditions, the total volume of sludge disposed in the basin was estimated at 6,254,345 m³, covering an area of about 1,000 ha (Artesium, 2024b). The Base Case analysis assumed a flow and migration path of about 17 km in the Main Reef.

The following can be noted from the series of simulations for alternative conceptual models and varied parameter values:

- The potential radiological impact on members of the public will manifest itself in only thousands to tens of thousands of years at a point 17 km away from the sludge disposal zone.
- The Base Case simulation using a realistic set of parameter values shows that, in all likelihood, the water ingestion doses will be below the dose limit of 1,000 μSv.year⁻¹.
- The variation in activity concentration between the 2016 and 2024 samples and the effect on the dose calculations highlight the importance of building a database of sludge radioanalytical results that can be used in subsequent evaluations and for decision-making. The results vary significantly between the two samples and the average between the two samples.
- The most significant variations were observed for different sets of K_d-values, which represent the partitioning of radionuclides between solids and liquids. The low K_d-values that represent little adsorption resulted in a significant radiological impact due to high source term release rates from the disposal zone. In addition, it also resulted in higher migration rates, which means the peak doses were reached at earlier times (10 times earlier). Higher K_d-values, on the other hand, have the opposite effect with peak doses reached at much later times (ten times later).
- The most significant variations were observed when using different sets of K_d-values, which determine how radionuclides partition between solids and liquids. Low K_d-values, which indicate limited adsorption, led to a considerable radiological impact because of the high source term release rates from the disposal zone. Additionally, these values resulted in faster migration, with peak doses occurring up to ten times sooner. Conversely, higher K_d-values had the opposite effect, causing peak doses to be reached much later—about ten times later.
- Any migration through the Wits Quartzite (Deep Confinement Zone) with its much lower permeability is almost none. No activity reaches the compliance point 17 km away from the disposal zone within the simulation period of 1,000,000 years. At a point 1 km away, the water ingestion doses are about 100 μSv.year⁻¹ after 1,000,000 years.

- Assuming an order of magnitude higher flux through the disposal zone results in a significantly faster source term release rate, which reduces the water ingestion dose to less than $100 \mu\text{Sv}\cdot\text{year}^{-1}$ and at earlier maximum times. Conversely, lower fluxes through the disposal zone resulted in increased doses at much later maximum times.
- The contribution from untreated AMD water to the water ingestion dose is not significant and results in a constant contribution after the plume release from the disposal zone have passed the compliance point.



5 Worker Safety Assessment Analysis

5.1 General

The purpose of this section is to present the safety assessment analysis results for exposure to workers (i.e., occupational exposure) induced by the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations. The basis for the safety assessment analysis is the regulatory framework presented in the assessment context presented in Section 2 and the system description presented in Section 3.

The section is structured as follows. Section 4.2 evaluates and presents the worker safety assessment analysis for the water treatment plant, while Section 4.3 evaluates and presents the safety assessment analysis associated with the sludge disposal operation.

5.2 Water Treatment Plant

5.2.1 General

The nature of the Water Treatment Plant is such that it may serve as a source of radiation exposure to workers (occupational exposure). The radiological characteristics of the material that contains naturally occurring radionuclides may differ within the different sections of the Water Treatment Plant, which means that exposure to workers performing activities within the different sections of the plant may potentially vary as well.

5.2.2 Exposure at the Water Treatment Plant

5.2.2.1 General

NRR (1997) provides guidelines for performing worker safety assessments. For this purpose, radiation surveys are conducted to establish the external gamma radiation and surface contamination. The surface contamination contributes to the dust inhalation pathway following resuspension. The results of these surveys serve as input into the worker safety assessment. The outcome of the assessment, in turn, serves as the basis for classifying designated areas according to the criteria presented in Section 2.2.7 into non-controlled, supervised and controlled areas (see Table 2.1). Given the wet nature of the water treatment plant, radon inhalation is not expected to make any contribution as part of the Source-Pathway-Receptor analysis approach.

The results presented here include the September 2016 survey (See Section 3.8.4.2) and the January 2025 survey of the Water Treatment Plant (see Section 3.8.4.3).

5.2.2.2 Methodological Approach

The radiation dose due to dust inhalation following resuspension from surface contamination was conservatively calculated by multiplying the α and β surface contamination values in $\text{Bq}\cdot\text{cm}^{-2}$ converted to $\text{Bq}\cdot\text{m}^{-3}$, with an inhalation rate of $1.2\text{ m}^3\cdot\text{hour}^{-1}$ and using dose conversion factors for particles with an AMAD of $1\mu\text{m}$ (most conservative). The dose conversion factors for $1\mu\text{m}$ particles with a Th/U ratio of 1:7 as provided in the Department of Mines and Petroleum (2010) were used, i.e. 0.0052. A conservative resuspension factor for the dust of $1\text{E-}6$ and an occupancy factor of 2,000 hours were assumed in the calculations.

5.2.2.3 September 2016 Survey Results

Table 3.8 provides the input data used for the assessment. The results are presented in Table 5.1, which show that on average for a 2,000-hour per annum exposure period the total effective dose is 0.27 mSv, with the 90th percentile of 0.46 mSv per annum. The maximum dose rate observed is 0.5 mSv per annum, which means that all areas at the DWS Eastern Basin Water Treatment Plant can be classified as uncontrolled areas as far as worker exposure is concerned (see Table 2.1 and Table 2.2). However, the background value (Claire Office) also results in a total dose of 0.5 mSv per annum, *which suggests very little to no contribution from the Water Treatment Plant in terms of external gamma radiation and inhalation doses to workers.*

5.2.2.4 January 2025 Survey Results

Table 3.10 provides the input data used for the assessment. The results are presented in Table 5.2, which show that on average for a 2,000-hour per annum exposure period the total effective dose is 0.35 mSv, with the 90th percentile of 0.43 mSv per annum. The maximum dose rate observed is 0.51 mSv per annum, which means that all areas at the DWS Eastern Basin Water Treatment Plant can be classified as uncontrolled areas as far as worker exposure is concerned (see Table 2.1 and Table 2.2). However, the background value (Christophor Office) also results in a total dose of 0.22 mSv per annum, *which suggests very little contribution from the Water Treatment Plant in terms of external gamma radiation and inhalation doses to workers.*

5.2.3 Discharge of Treated Water to the Blesbok Spruit

The treated water overflows from the thickeners and flows to the treated water sump. Water overflowing from the sump flows over a weir and is then discharged by gravity to the Blesbok Spruit (see Figure 5.1). Once discharged, the treated serve as a source of radiation exposure to members of the public (see Section 4.2.2), but not to workers.



Figure 5.1 Photo showing the discharge of the treated water from the Water Treatment Plant over the weir into the environment.

Table 5.1 Summary of the worker radiation exposure levels as calculated from the survey results presented in Table 3.8 for the DWS Eastern Basin Water Treatment Plant. Note that the background values (Claire Office) were subtracted from the data.

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Claire Office (Background)	0.01	0.08	0.25	0.09	900	0.0009	0.011232	0.50	0.511
Guard House	0	0.07	0.11	0.07	700	0.0007	0.008736	0.22	0.229
Treated Water Pump Station	0	0.08	0.11	0.08	800	0.0008	0.009984	0.22	0.230
Treated Water Sump	0	0.06	0.17	0.06	600	0.0006	0.007488	0.34	0.347
Thickener No.2	0.01	0.05	0.09	0.06	600	0.0006	0.007488	0.18	0.187
Valve	0.02	0.03	0.23	0.05	500	0.0005	0.00624	0.46	0.466
Thickener No.2	0.01	0.04	0.07	0.05	500	0.0005	0.00624	0.14	0.146
Utility Water Reticulation	0	0	0.09	0	0	0	0	0.18	0.180
Thickener No.3	0.01	0.2	0.11	0.21	2100	0.0021	0.026208	0.22	0.246
Poly Dosing Building	0.02	0	0.15	0.02	200	0.0002	0.002496	0.3	0.302
Thickener No.3	0	0.06	0.09	0.06	600	0.0006	0.007488	0.18	0.187
Thickener No.1	0	0.04	0.03	0.04	400	0.0004	0.004992	0.06	0.065
Thickener No.1	0	0	0.23	0	0	0	0	0.46	0.460
Thickener No.2	0	0.03	0.17	0.03	300	0.0003	0.003744	0.34	0.344
Thickener No.1	0	0	0.11	0	0	0	0	0.22	0.220
Thickener No.3	0.01	0.02	0.17	0.03	300	0.0003	0.003744	0.34	0.344
Thickener No.3	0	0.03	0.23	0.03	300	0.0003	0.003744	0.46	0.464
Eastern Corner	0	0.03	0.11	0.03	300	0.0003	0.003744	0.22	0.224
Inspection Manhole	0.02	0	0.17	0.02	200	0.0002	0.002496	0.34	0.342
Generator Room 2	0	0	0.17	0	0	0	0	0.34	0.340
South Corner	0	0.04	0.17	0.04	400	0.0004	0.004992	0.34	0.345
Shaft Pump Station	0	0.04	0.23	0.04	400	0.0004	0.004992	0.46	0.465
VFD & MV Room	0	0.1	0.04	0.1	1000	0.001	0.01248	0.08	0.092
MCC Room	0.01	0	0.23	0.01	100	0.0001	0.001248	0.46	0.461
Limestone Dosing	0	0.02	0.23	0.02	200	0.0002	0.002496	0.46	0.462
Limestone Dosing	0	0	0.21	0	0	0	0	0.42	0.420
Quick Lime Dosing	0.01	0.06	0.01	0.07	700	0.0007	0.008736	0.02	0.029
Quick Lime Dosing	0.01	0	0.21	0.01	100	0.0001	0.001248	0.42	0.421

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1 µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Quick Lime Dosing	0.01	0.06	0.06	0.07	700	0.0007	0.008736	0.12	0.129
Quick Lime Dosing	0	0.06	0.21	0.06	600	0.0006	0.007488	0.42	0.427
Lime Dosing Pipe	0.01	0.06	0.23	0.07	700	0.0007	0.008736	0.46	0.469
Generator Room 1	0.02	0	0.01	0.02	200	0.0002	0.002496	0.02	0.022
Generator Room 2	0.02	0.22	0.17	0.24	2400	0.0024	0.029952	0.34	0.370
Between Generator rooms 1 & 2	0	0.03	0.03	0.03	300	0.0003	0.003744	0.06	0.064
Limestone Dosing Pipe	0	0	0.06	0	0	0	0	0.12	0.120
Plant Drain	0.03	0.04	0.09	0.07	700	0.0007	0.008736	0.18	0.189
Steps at Plant Drain	0	0.04	0.07	0.04	400	0.0004	0.004992	0.14	0.145
Pipes from the Shaft Pump Station	0	0.07	0.09	0.07	700	0.0007	0.008736	0.18	0.189
Pipes from the Shaft Pump Station	0	0.03	0.01	0.03	300	0.0003	0.003744	0.02	0.024
Steps to Thickening Reactors	0.01	0	0.21	0.01	100	0.0001	0.001248	0.42	0.421
Inspection Manhole	0	0.01	0.17	0.01	100	0.0001	0.001248	0.34	0.341
Corner of Thickening Reactors	0	0.02	0.26	0.02	200	0.0002	0.002496	0.52	0.522
Thickening Reactors	0.01	0.03	0.23	0.04	400	0.0004	0.004992	0.46	0.465
Thickening Reactors	0	0.14	0.09	0.14	1400	0.0014	0.017472	0.18	0.197
Thickening Reactors	0	0.05	0.06	0.05	500	0.0005	0.00624	0.12	0.126
Thickening Reactors	0	0	0.14	0	0	0	0	0.28	0.280
Thickening Reactors	0	0.05	0.16	0.05	500	0.0005	0.00624	0.32	0.326
Thickening Reactors	0	0.07	0.19	0.07	700	0.0007	0.008736	0.38	0.389
Thickening Reactors	0	0.01	0.23	0.01	100	1E-04	0.001248	0.46	0.461
Thickening Reactors	0	0.01	0.2	0.01	100	1E-04	0.001248	0.4	0.401
Thickening Reactors	0	0	0.01	0	0	0	0	0.02	0.020
Thickening Reactors	0	0	0.03	0	0	0	0	0.06	0.060
Thickening Reactors	0	0.05	0.16	0.05	500	0.0005	0.00624	0.32	0.326
Thickening Reactors	0	0	0.03	0	0	0	0	0.06	0.060
Thickening Reactors	0	0.06	0.24	0.06	600	0.0006	0.007488	0.48	0.487
Thickening Reactors	0	0	0.11	0	0	0	0	0.22	0.220
Thickening Reactors	0	0.04	0.14	0.04	400	0.0004	0.004992	0.28	0.285
Thickening Reactors	0	0	0.15	0	0	0	0	0.3	0.300
Thickening Reactors	0.01	0.02	0.17	0.03	300	0.0003	0.003744	0.34	0.344

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1 µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Thickening Reactors	0	0	0.23	0	0	0	0	0.46	0.460
Thickening Reactors	0	0	0.17	0	0	0	0	0.34	0.340
Thickening Reactors	0	0.02	0.03	0.02	200	0.0002	0.002496	0.06	0.062
Thickening Reactors	0	0.06	0.06	0.06	600	0.0006	0.007488	0.12	0.127
Thickening Reactors	0.02	0.13	0.01	0.15	1500	0.0015	0.01872	0.02	0.039
Thickening Reactors	0	0.03	0.16	0.03	300	0.0003	0.003744	0.32	0.324
Thickening Reactors	0	0.05	0.11	0.05	500	0.0005	0.00624	0.22	0.226
Thickening Reactors	0.02	0.05	0.14	0.07	700	0.0007	0.008736	0.28	0.289
Thickening Reactors	0	0.06	0.13	0.06	600	0.0006	0.007488	0.26	0.267
Canteen	0	0	0.06	0	0	0	0	0.12	0.120
Workshops	0	0.05	0.06	0.05	500	0.0005	0.00624	0.12	0.126
Workshops	0	0.03	0.18	0.03	300	0.0003	0.003744	0.36	0.364
Workshops	0	0.04	0.16	0.04	400	0.0004	0.004992	0.32	0.325
Workshops	0	0.02	0.15	0.02	200	0.0002	0.002496	0.3	0.302
Workshops	0	0.04	0.11	0.04	400	0.0004	0.004992	0.22	0.225
Offices Reception	0	0.06	0.16	0.06	600	0.0006	0.007488	0.32	0.327
Offices	0	0.07	0.08	0.07	700	0.0007	0.008736	0.16	0.169
Offices	0.02	0.06	0.23	0.08	800	0.0008	0.009984	0.46	0.470
Offices	0.01	0	0.19	0.01	100	0.0001	0.001248	0.38	0.381
Offices	0.01	0.03	0.12	0.04	400	0.0004	0.004992	0.24	0.245
Offices Control Room	0	0.06	0.02	0.06	600	0.0006	0.007488	0.04	0.047
Offices Control Room	0	0.08	0.03	0.08	800	0.0008	0.009984	0.06	0.070
Average	0.004	0.039	0.132	0.043	430.000	0.000	0.0054	0.264	0.269
Maximum	0.030	0.220	0.260	0.240	2400.000	0.002	0.0300	0.520	0.522
Minimum	0.000	0.000	0.010	0.000	0.000	0.000	0.0000	0.020	0.020
90 th Percentile	0.020	0.070	0.230	0.071	710.000	0.001	0.0089	0.460	0.463

Table 5.2 Summary of the worker radiation exposure levels as calculated from the survey results presented in Table 3.8 for the DWS Eastern Basin Water Treatment Plant. Note that the background values (Christopher's Office) were subtracted from the data.

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Christopher Office (Background)	0.000	0.070	0.100	0.120	1200	0.001	0.015	0.200	0.215
Security office main gate	0.000	0.060	0.140	0.180	1800	0.002	0.022	0.280	0.302
Security office main gate	0.000	0.070	0.160	0.190	1900	0.002	0.024	0.320	0.344
Security office main gate	0.000	0.120	0.150	0.200	2000	0.002	0.025	0.300	0.325
Utility water pump station outside	0.000	0.040	0.160	0.200	2000	0.002	0.025	0.320	0.345
Utility water pump station outside	0.010	0.060	0.170	0.190	1900	0.002	0.024	0.340	0.364
Utility water pump station outside	0.000	0.070	0.170	0.180	1800	0.002	0.022	0.340	0.362
Polydosing storage area	0.000	0.060	0.200	0.190	1900	0.002	0.024	0.400	0.424
Polydosing storage area	0.000	0.060	0.160	0.170	1700	0.002	0.021	0.320	0.341
Polydosing storage area	0.000	0.110	0.170	0.170	1700	0.002	0.021	0.340	0.361
Polydosing storage area	0.000	0.060	0.210	0.190	1900	0.002	0.024	0.420	0.444
Weighbridge office	0.000	0.070	0.180	0.190	1900	0.002	0.024	0.360	0.384
Weighbridge office	0.000	0.060	0.140	0.160	1600	0.002	0.020	0.280	0.300
Weighbridge office	0.010	0.080	0.160	0.170	1700	0.002	0.021	0.320	0.341
Weighbridge office	0.000	0.080	0.150	0.130	1300	0.001	0.016	0.300	0.316
Weighbridge office	0.010	0.110	0.110	0.140	1400	0.001	0.017	0.220	0.237
Reactor 3 top	0.000	0.060	0.140	0.160	1600	0.002	0.020	0.280	0.300
Reactor 3 top	0.010	0.040	0.160	0.170	1700	0.002	0.021	0.320	0.341
Reactor 3 top	0.000	0.060	0.170	0.190	1900	0.002	0.024	0.340	0.364
Reactor 3 top	0.000	0.080	0.180	0.160	1600	0.002	0.020	0.360	0.380
Reactor 3 top	0.000	0.050	0.140	0.200	2000	0.002	0.025	0.280	0.305
Reactor 3 top	0.000	0.060	0.140	0.160	1600	0.002	0.020	0.280	0.300
Reactor 3 top	0.000	0.080	0.160	0.170	1700	0.002	0.021	0.320	0.341
Reactor 3 top	0.000	0.100	0.110	0.140	1400	0.001	0.017	0.220	0.237
Reactor 3 top	0.000	0.050	0.140	0.110	1100	0.001	0.014	0.280	0.294
Reactor 3 top	0.000	0.070	0.140	0.160	1600	0.002	0.020	0.280	0.300
Reactor 3 top	0.000	0.100	0.160	0.190	1900	0.002	0.024	0.320	0.344
Reactor 3 top	0.000	0.060	0.190	0.210	2100	0.002	0.026	0.380	0.406

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Reactor 2 top	0.000	0.050	0.190	0.190	1900	0.002	0.024	0.380	0.404
Reactor 2 top	0.000	0.080	0.160	0.160	1600	0.002	0.020	0.320	0.340
Reactor 2 top	0.000	0.080	0.140	0.170	1700	0.002	0.021	0.280	0.301
Reactor 2 top	0.000	0.060	0.130	0.140	1400	0.001	0.017	0.260	0.277
Reactor 2 top	0.010	0.050	0.140	0.160	1600	0.002	0.020	0.280	0.300
Reactor 2 top	0.000	0.080	0.160	0.150	1500	0.002	0.019	0.320	0.339
Reactor 2 top	0.000	0.040	0.140	0.130	1300	0.001	0.016	0.280	0.296
Reactor 2 top	0.000	0.080	0.130	0.140	1400	0.001	0.017	0.260	0.277
Reactor 2 top	0.000	0.060	0.100	0.110	1100	0.001	0.014	0.200	0.214
Reactor 2 top	0.000	0.050	0.090	0.100	1000	0.001	0.012	0.180	0.192
Reactor 2 top	0.000	0.090	0.110	0.110	1100	0.001	0.014	0.220	0.234
Reactor 2 top	0.000	0.040	0.110	0.110	1100	0.001	0.014	0.220	0.234
Reactor 1 top	0.000	0.120	0.140	0.160	1600	0.002	0.020	0.280	0.300
Reactor 1 top	0.000	0.050	0.110	0.140	1400	0.001	0.017	0.220	0.237
Reactor 1 top	0.000	0.060	0.100	0.120	1200	0.001	0.015	0.200	0.215
Reactor 1 top	0.000	0.060	0.140	0.160	1600	0.002	0.020	0.280	0.300
Reactor 1 top	0.010	0.050	0.130	0.140	1400	0.001	0.017	0.260	0.277
Reactor 1 top	0.000	0.080	0.160	0.170	1700	0.002	0.021	0.320	0.341
Reactor 1 top	0.000	0.040	0.140	0.130	1300	0.001	0.016	0.280	0.296
Reactor 1 top	0.000	0.100	0.130	0.120	1200	0.001	0.015	0.260	0.275
Reactor 1 top	0.010	0.030	0.120	0.140	1400	0.001	0.017	0.240	0.257
Reactor 1 top	0.000	0.070	0.110	0.130	1300	0.001	0.016	0.220	0.236
Reactor 1 top	0.000	0.030	0.090	0.110	1100	0.001	0.014	0.180	0.194
Reactor 1 top	0.000	0.040	0.100	0.140	1400	0.001	0.017	0.200	0.217
Shaft pump station	0.000	0.070	0.160	0.170	1700	0.002	0.021	0.320	0.341
Shaft pump station	0.000	0.050	0.170	0.180	1800	0.002	0.022	0.340	0.362
Shaft pump station	0.000	0.060	0.140	0.190	1900	0.002	0.024	0.280	0.304
Shaft pump station	0.000	0.060	0.130	0.140	1400	0.001	0.017	0.260	0.277
Shaft pump station	0.000	0.050	0.160	0.170	1700	0.002	0.021	0.320	0.341
VFD building outside	0.000	0.060	0.160	0.170	1700	0.002	0.021	0.320	0.341
VFD building outside	0.000	0.050	0.170	0.190	1900	0.002	0.024	0.340	0.364

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
VFD building outside	0.000	0.110	0.210	0.210	2100	0.002	0.026	0.420	0.446
VFD building outside	0.000	0.060	0.200	0.190	1900	0.002	0.024	0.400	0.424
MCC building outside	0.000	0.050	0.190	0.180	1800	0.002	0.022	0.380	0.402
MCC building outside	0.000	0.050	0.200	0.190	1900	0.002	0.024	0.400	0.424
MCC building outside	0.000	0.050	0.210	0.220	2200	0.002	0.027	0.420	0.447
MCC building outside	0.000	0.130	0.200	0.210	2100	0.002	0.026	0.400	0.426
Generator 1 building outside	0.000	0.060	0.170	0.200	2000	0.002	0.025	0.340	0.365
Generator 1 building outside	0.000	0.050	0.160	0.170	1700	0.002	0.021	0.320	0.341
Generator 1 building outside	0.000	0.110	0.150	0.180	1800	0.002	0.022	0.300	0.322
Generator 2 building outside	0.000	0.100	0.140	0.170	1700	0.002	0.021	0.280	0.301
Generator 2 building outside	0.000	0.100	0.170	0.160	1600	0.002	0.020	0.340	0.360
Generator 2 building outside	0.000	0.110	0.190	0.150	1500	0.002	0.019	0.380	0.399
Limestone and lime dosing area	0.000	0.050	0.170	0.200	2000	0.002	0.025	0.340	0.365
Limestone and lime dosing area	0.000	0.050	0.160	0.210	2100	0.002	0.026	0.320	0.346
Limestone and lime dosing area	0.000	0.040	0.150	0.190	1900	0.002	0.024	0.300	0.324
Limestone and lime dosing area	0.000	0.070	0.160	0.170	1700	0.002	0.021	0.320	0.341
Limestone and lime dosing area	0.000	0.100	0.170	0.160	1600	0.002	0.020	0.340	0.360
Limestone and lime dosing area	0.000	0.040	0.140	0.130	1300	0.001	0.016	0.280	0.296
Limestone and lime dosing area	0.000	0.050	0.150	0.140	1400	0.001	0.017	0.300	0.317
Limestone and lime dosing area	0.000	0.110	0.160	0.170	1700	0.002	0.021	0.320	0.341
Limestone and lime dosing area	0.000	0.130	0.170	0.190	1900	0.002	0.024	0.340	0.364
Limestone and lime dosing area	0.000	0.130	0.180	0.200	2000	0.002	0.025	0.360	0.385
Mechanical workshop	0.000	0.070	0.160	0.170	1700	0.002	0.021	0.320	0.341
Mechanical workshop	0.000	0.110	0.170	0.160	1600	0.002	0.020	0.340	0.360
Mechanical workshop	0.010	0.090	0.180	0.150	1500	0.002	0.019	0.360	0.379
Mechanical workshop	0.000	0.080	0.150	0.140	1400	0.001	0.017	0.300	0.317
Mechanical workshop	0.000	0.100	0.160	0.150	1500	0.002	0.019	0.320	0.339
Electrical workshop	0.000	0.100	0.190	0.200	2000	0.002	0.025	0.380	0.405
Electrical workshop	0.010	0.100	0.200	0.180	1800	0.002	0.022	0.400	0.422
Electrical workshop	0.000	0.030	0.160	0.170	1700	0.002	0.021	0.320	0.341
Electrical workshop	0.000	0.070	0.170	0.160	1600	0.002	0.020	0.340	0.360

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Electrical workshop	0.000	0.140	0.190	0.170	1700	0.002	0.021	0.380	0.401
Canteen area	0.000	0.070	0.170	0.180	1800	0.002	0.022	0.340	0.362
Canteen area	0.000	0.130	0.180	0.190	1900	0.002	0.024	0.360	0.384
Canteen area	0.000	0.110	0.190	0.170	1700	0.002	0.021	0.380	0.401
Canteen area	0.010	0.150	0.200	0.200	2000	0.002	0.025	0.400	0.425
Canteen area	0.010	0.150	0.210	0.200	2000	0.002	0.025	0.420	0.445
Outside ablution block bathrooms	0.000	0.100	0.160	0.170	1700	0.002	0.021	0.320	0.341
Outside ablution block bathrooms	0.000	0.050	0.140	0.160	1600	0.002	0.020	0.280	0.300
Outside ablution block bathrooms	0.000	0.080	0.150	0.170	1700	0.002	0.021	0.300	0.321
Outside ablution block bathrooms	0.000	0.130	0.170	0.190	1900	0.002	0.024	0.340	0.364
Outside ablution block bathrooms	0.010	0.100	0.180	0.170	1700	0.002	0.021	0.360	0.381
Thickener dam 1	0.000	0.170	0.190	0.160	1600	0.002	0.020	0.380	0.400
Thickener dam1	0.010	0.110	0.120	0.140	1400	0.001	0.017	0.240	0.257
Thickener dam 1	0.000	0.130	0.140	0.160	1600	0.002	0.020	0.280	0.300
Thickener dam 1	0.010	0.110	0.190	0.170	1700	0.002	0.021	0.380	0.401
Thickener dam 1	0.000	0.130	0.130	0.180	1800	0.002	0.022	0.260	0.282
Thickener dam 2	0.000	0.130	0.160	0.190	1900	0.002	0.024	0.320	0.344
Thickener dam 2	0.000	0.170	0.170	0.190	1900	0.002	0.024	0.340	0.364
Thickener dam 2	0.000	0.150	0.190	0.160	1600	0.002	0.020	0.380	0.400
Thickener dam 2	0.000	0.090	0.180	0.170	1700	0.002	0.021	0.360	0.381
Thickener dam 2	0.000	0.130	0.140	0.160	1600	0.002	0.020	0.280	0.300
Thickener dam 3	0.010	0.120	0.160	0.170	1700	0.002	0.021	0.320	0.341
Thickener dam 3	0.010	0.160	0.117	0.160	1600	0.002	0.020	0.234	0.254
Thickener dam 3	0.010	0.160	0.160	0.190	1900	0.002	0.024	0.320	0.344
Thickener dam 3	0.000	0.080	0.140	0.130	1300	0.001	0.016	0.280	0.296
Thickener dam 3	0.010	0.080	0.150	0.140	1400	0.001	0.017	0.300	0.317
Treated water sump dam	0.000	0.100	0.170	0.180	1800	0.002	0.022	0.340	0.362
Treated water sump dam	0.000	0.140	0.160	0.170	1700	0.002	0.021	0.320	0.341
Treated water sump dam	0.000	0.070	0.170	0.160	1600	0.002	0.020	0.340	0.360
Treated water sump dam	0.000	0.100	0.140	0.140	1400	0.001	0.017	0.280	0.297
Treated water sump dam	0.000	0.110	0.200	0.190	1900	0.002	0.024	0.400	0.424

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Laboratory	0.000	0.120	0.140	0.160	1600	0.002	0.020	0.280	0.300
Laboratory	0.000	0.130	0.150	0.170	1700	0.002	0.021	0.300	0.321
Laboratory	0.000	0.070	0.170	0.180	1800	0.002	0.022	0.340	0.362
Christopher office	0.000	0.130	0.200	0.180	1800	0.002	0.022	0.400	0.422
Christopher office	0.000	0.140	0.210	0.200	2000	0.002	0.025	0.420	0.445
Christopher office	0.000	0.090	0.240	0.210	2100	0.002	0.026	0.480	0.506
Boardroom	0.000	0.120	0.160	0.190	1900	0.002	0.024	0.320	0.344
Boardroom	0.000	0.110	0.190	0.200	2000	0.002	0.025	0.380	0.405
Boardroom	0.000	0.110	0.200	0.210	2100	0.002	0.026	0.400	0.426
Office 2	0.000	0.130	0.180	0.190	1900	0.002	0.024	0.360	0.384
Office 2	0.000	0.130	0.170	0.200	2000	0.002	0.025	0.340	0.365
Office 2	0.000	0.130	0.160	0.210	2100	0.002	0.026	0.320	0.346
Office 3	0.000	0.070	0.230	0.170	1700	0.002	0.021	0.460	0.481
Office 3	0.000	0.130	0.200	0.180	1800	0.002	0.022	0.400	0.422
Office 3	0.000	0.130	0.190	0.170	1700	0.002	0.021	0.380	0.401
Kitchen	0.000	0.160	0.170	0.150	1500	0.002	0.019	0.340	0.359
Kitchen	0.000	0.150	0.160	0.140	1400	0.001	0.017	0.320	0.337
Kitchen	0.000	0.150	0.150	0.160	1600	0.002	0.020	0.300	0.320
Office 1	0.000	0.120	0.230	0.250	2500	0.003	0.031	0.460	0.491
Office 1	0.000	0.090	0.200	0.210	2100	0.002	0.026	0.400	0.426
Office 1	0.010	0.080	0.190	0.210	2100	0.002	0.026	0.380	0.406
Laboratory Office	0.000	0.130	0.190	0.170	1700	0.002	0.021	0.380	0.401
Laboratory Office	0.000	0.150	0.200	0.180	1800	0.002	0.022	0.400	0.422
Laboratory Office	0.000	0.150	0.210	0.190	1900	0.002	0.024	0.420	0.444
Reception	0.000	0.130	0.240	0.190	1900	0.002	0.024	0.480	0.504
Reception	0.000	0.110	0.210	0.200	2000	0.002	0.025	0.420	0.445
Reception	0.000	0.190	0.230	0.230	2300	0.002	0.029	0.460	0.489
Control room	0.000	0.130	0.130	0.160	1600	0.002	0.020	0.260	0.280
Control room	0.000	0.120	0.140	0.150	1500	0.002	0.019	0.280	0.299
Control room	0.000	0.120	0.160	0.150	1500	0.002	0.019	0.320	0.339
Control room	0.000	0.060	0.060	0.090	900	0.001	0.011	0.120	0.131

Description of the Area	Electra Measurements			Surface contact			Annual Equivalent Inhalation Dose (1µm)	External Gamma Dose	Total Effective Dose
	α	β	Dose Rate (1m)						
	Bq.cm ⁻²		µSv.h ⁻¹	Bq.cm ⁻²	Bq.m ⁻²	Bq.m ⁻³	mSv.year ⁻¹		
Sludge pump station basement	0.000	0.110	0.070	0.110	1100	0.001	0.014	0.140	0.154
Sludge pump station basement	0.000	0.110	0.110	0.140	1400	0.001	0.017	0.220	0.237
Sludge pump station basement	0.000	0.150	0.120	0.130	1300	0.001	0.016	0.240	0.256
Sludge pump station basement	0.000	0.150	0.140	0.130	1300	0.001	0.016	0.280	0.296
Sludge pump station basement	0.000	0.080	0.160	0.170	1700	0.002	0.021	0.320	0.341
Sludge pump station basement	0.010	0.150	0.170	0.190	1900	0.002	0.024	0.340	0.364
Sludge pump station basement	0.000	0.120	0.160	0.170	1700	0.002	0.021	0.320	0.341
Sludge pump station basement	0.000	0.080	0.170	0.190	1900	0.002	0.024	0.340	0.364
Sludge pump station basement	0.000	0.030	0.180	0.200	2000	0.002	0.025	0.360	0.385
Sludge pump station basement	0.000	0.110	0.190	0.210	2100	0.002	0.026	0.380	0.406
Sludge pump station basement	0.000	0.100	0.200	0.190	1900	0.002	0.024	0.400	0.424
Sludge pump station basement	0.000	0.260	0.230	0.240	2400	0.002	0.030	0.460	0.490
Average	0.001	0.093	0.162	0.170	1698	0.002	0.021	0.324	0.346
Maximum	0.010	0.260	0.240	0.250	2500	0.003	0.031	0.480	0.506
Minimum	0.000	0.030	0.060	0.090	900	0.001	0.011	0.120	0.131
90 th Percentile	0.010	0.148	0.200	0.200	2000	0.002	0.025	0.400	0.425

5.2.4 Untreated Water

Workers at the Water Treatment Plant are not expected to come in direct contact with the untreated water (through immersion) or to ingest some of the untreated water either as a source of water or unintentionally. Direct ingestion of water or external gamma radiation as a result of the untreated water is, therefore, not considered a viable exposure route for worker exposure.

To evaluate the potential contribution of the untreated AMD Water, the following is assumed. It is only certain workers operating in certain sections of the Water Treatment Plant that may potentially come in contact with untreated AMD Water. The only potential exposure routes of concern are accidental ingestion of water and the inhalation and ingestion of water vapour that may be present. Assuming that a specific worker as the most exposed person working at the plant ingests 50 mL AMD Water in this way every hour for 2,000 per year. This equates to a water ingestion rate of 100 L.year⁻¹.

Table 4.3 presents the water ingestion doses to different age groups, which shows that an adult AMD Water ingestion rate of 600 L.year⁻¹ would result in an ingestion dose of about 0.4 mSv.year⁻¹. This means the 100 L.year⁻¹ ingestion rate would result in an annual ingestion dose of about 0.07 mSv.year⁻¹. Even an ingestion rate of 150 L.year⁻¹ (or 75 mL per day) would still result in an ingestion dose of less than 0.1 mSv.year⁻¹.

5.2.5 Maintenance Activities

Section 3.9.2 describes the maintenance activities that are required at the Water Treatment Plant, with additional information presented in AECOM (2015a). Specific lines that need maintenance or repair are taken out of operations, without affecting the other operating lines in the process. Flushing of components is done when in maintenance mode, while pigging is done for those components that transfer sludge into the system.

No data is available at this stage to estimate what the level of contamination would be in different components of the system, which will differ for those in contact with AMD water, treated water or sludge generated during the water treatment process. It might be that the dose rates are similar to those observed during the normal operating conditions (see Section 5.2.2), but shorter exposure periods and thus lower dose rate levels for the maintenance activities.

It is, therefore, proposed that dose rate measurements be taken during the maintenance activities until it can be demonstrated with certainty that the maintenance activities performed in the different sections of the plant meet the necessary regulatory compliance criteria. The procedures to follow can be included in the Method Statement and safety files for approvals before maintenance work commences (see Section 6.3).

5.2.6 Discussion

The most recent results available for worker exposure suggest that on average, the exposure levels are in the order of 0.35 mSv.year⁻¹ (with the 90th percentile of 0.43 mSv.year⁻¹), which is above the dose constraint of 0.25 mSv.year⁻¹ for members of the public (as workers). However, if the background value of 0.2 mSv.year⁻¹ is subtracted from the measured values, then it is clear that the Water Treatment Plant itself makes little contribution to the total effective dose to workers at the plant.

The results showed that under normal operating conditions workers at the Water Treatment Plant do not have to be registered as Occupationally Exposed Persons (OEP), with a non-controlled area classification for all areas of the plant. The standard 2,000 hours per annum occupancy was assumed, which means that more realistic occupancy factors can be defined for each section of the plant that will reduce the

calculated exposure even further (see Section 6.3). In addition, the treated water released to the Blesbok Spruit does not pose a radiation exposure condition to the workers.

It is unlikely that a worker at the Water Treatment Plant would ingest a significant volume of untreated AMD Water regularly. Assuming conservative conditions, the potential water ingestion dose is less than less than $0.1 \text{ mSv}\cdot\text{year}^{-1}$.

No data are available for worker radiation exposure conditions during maintenance activities, although it is expected to be lower than during normal operating conditions due to shorter exposure periods. In addition, equipment and components are flushed during maintenance, while pigging is applied in pipelines used to transfer sludge. It is proposed that surveys be conducted during maintenance activities.

5.3 Sludge Management

5.3.1 General

The conditions and assumptions for the HDS disposal operation were presented in Section 3.4, which suggests that the sludge is directly transferred *via* an HDPE pipeline from the Water Treatment Plant on the surface to the point of disposal in the basin through the Grootvlei No. 3 Shaft, No. 4 Shaft or the deep sludge disposal boreholes. Therefore, the HDS itself is not handled during the emplacement operation and workers also do not come in direct contact with the sludge. This means that occupational exposure of workers to the sludge disposal operation is not possible and, therefore, does not pose a radiation exposure condition to workers during normal operating conditions.

5.3.2 Maintenance Activities

All maintenance activities associated with the sludge disposal operations are done at the surface after pumps and pipelines are extracted from the shaft. Workers are not expected to go down in the shafts themselves for maintenance activities.

Like the Water Treatment Plant itself, no data is available at this stage to estimate what the level of contamination would be in the pumps or pipelines extracted from underground for maintenance. Therefore, it is proposed that dose rate measurements be taken during the maintenance activities until it can be demonstrated with certainty that the maintenance activities performed on the pumps and pipelines meet the necessary clearance criteria. This should include the collection of samples of scales that might have accumulated on any of the equipment for full-spectrum analysis (see Section 6.3).

5.3.3 Discussion

Workers involved in the sludge disposal operations are limited to maintenance activities of the pumps and pipelines, which are done at the surface. Workers do not have to be registered as Occupationally Exposed Persons (OEP), but a survey programme is proposed to gather data to estimate the level of contamination that can be expected on the pumps and pipelines during maintenance activities, including full-spectrum analysis of scales accumulated on equipment.



6 Conclusions and Recommendations

6.1 General

Consistent with the purpose and objective of the assessment (see Section 2.3.3), this report evaluated and presented the radiological public and worker safety assessment for the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations. The primary objective was to demonstrate to the NNR and other stakeholders that workers and members of the public are not exposed to levels of ionising radiation induced by the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations that exceed the regulatory compliance criteria established for radiation exposure as defined in Section 2.2. The secondary objective was to show that the potential levels of ionising radiation from the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations adhere to the criteria for exemption from regulatory control as defined in Section 2.2.

6.2 Conclusions

6.2.1 Public Safety Assessment Analysis

The following conclusions were drawn from the public safety assessment analysis for the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations, which can be divided into the Water Treatment Plant and the sludge disposal operations:

- Due to the physical security measures implemented and maintained at the Water Treatment Plant, uncontrolled public access is not possible, with the result that the plant itself does not serve as a source of radiation exposure to members of the public.
- The release of treated water to the Blesbok Spruit may serve as a source of radiation exposure to members of the public. However, it was demonstrated that without accounting for dilution, the potential dose to members of the public could still be significant and exceed the public dose constraint of $250 \mu\text{Sv}\cdot\text{year}^{-1}$. If water abstracted from the Blesbok Spruit is used as the sole source of water to sustain a farm system, the doses could even approach the dose limit of $1,000 \mu\text{Sv}\cdot\text{year}^{-1}$. Accounting for dilution in the Blesbok Spruit reduces the total effective dose to less than $20 \mu\text{Sv}\cdot\text{year}^{-1}$.
- Given the current understanding of the sludge disposal operation in the Eastern Basin void, along with the associated hydrogeological and coupled geochemical conceptual model, a complete Source-Pathway-Receptor linkage, with the public as the final receptor, remains uncertain and may only materialise after 10,000 years. For a realistic set of parameter values, the expected water ingestion dose for this timeframe is less than $1,000 \mu\text{Sv}\cdot\text{year}^{-1}$.

6.2.2 Worker Safety Assessment Analysis

The following conclusions were drawn from the worker safety assessment analysis for the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations, which can be divided into the Water Treatment Plant and the sludge disposal operations, including normal operations and accident conditions:

- Given the observed and expected radiation exposure conditions associated with the DWS Eastern Basin Water Treatment Plant and Sludge Management Operations, workers do not have to be registered as OEP.

- The treated water is discharged by gravity from the treated water sump into the Blesbok Spruit, with the result that workers are not further exposed to the treated water (i.e., no radiological impact to workers). This means that all areas at the DWS Eastern Basin Water Treatment Plant can be classified as uncontrolled areas (see Section 2.2.7).
- The results from the surface contamination and gamma survey suggest that on average, the exposure levels are in the order of $0.35 \text{ mSv}\cdot\text{year}^{-1}$ (with the 90th percentile of $0.43 \text{ mSv}\cdot\text{year}^{-1}$), which is above the dose constraint of $0.25 \text{ mSv}\cdot\text{year}^{-1}$ for members of the public (as workers). However, if the background value of $0.2 \text{ mSv}\cdot\text{year}^{-1}$ is subtracted from the measured values, then it is clear that the Water Treatment Plant itself makes little contribution to the total effective dose to workers at the plant.
- No data are available for worker radiation exposure conditions during maintenance activities, although it is expected to be lower than during normal operating conditions due to shorter exposure periods. In addition, equipment and components are flushed during maintenance, while pigging is applied in pipelines used to transfer sludge. It is proposed that surveys be conducted during maintenance activities.

6.2.3 General Conclusion

The full-spectrum radioanalysis of the sludge reveals radionuclide levels exceeding $500 \text{ Bq}\cdot\text{kg}^{-1}$, which surpasses the threshold for exemption from regulatory controls. Additionally, the projected radiation doses to the public, including non-OEP workers, exceed the dose constraint of $250 \mu\text{Sv}\cdot\text{year}^{-1}$. As a result, it cannot be confidently recommended to grant exemption from regulatory controls as stipulated in Regulation 388 and detailed in Section 2.2 of this report. Section 6.3 offers specific recommendations aimed at obtaining a more complete record of activity concentrations in the sludge, as well as untreated and treated water, to enhance confidence in the assessment results.

6.3 Recommendations

Due to historical mining and associated disturbed underlying geology, ingress of water from the surface and the subsequent abstraction of water to maintain the ECL, the conceptual hydrogeological and coupled geochemical model of the Eastern Basin is considerably more complex than what is portrayed by Exigo Sustainability (2017b). This led to the development of a comprehensive hydrogeological flow and contaminant migration model by Artesium (2024b), which provided significant insight into understanding the sludge disposal operations.

- It is recommended that the model developed by Artesium (2024b) be maintained and updated as required with improved monitoring data and information, which will lead to a greater level of certainty in the sludge disposal operation.

The Directive by DWS (Ref: 16/2/7/C231/C068) already requires the implementation of a comprehensive geohydrological and geochemical monitoring programme, with a wide spectrum of variables to be assessed on a daily and weekly basis (including Uranium). Therefore:

- It is recommended that this monitoring be continued in line with the Directive and to the satisfaction of the DWS.

In addition to recommended monitoring, it is recommended that the following be included in the monitoring programme to facilitate radiation protection for workers and members of the public and to comply with the NNR recommendation for baseline monitoring as outlined in RG-002:

- Full-spectrum analysis, including total uranium and thorium, of the AMD water abstracted from the

Eastern Basin. The full spectrum analysis (U-238, U-235, Th-232 and their progeny) should be repeated annually, while the total uranium and thorium analysis should be repeated monthly.

- Full-spectrum analysis, including total uranium and thorium, of the sludge generated in the water treatment plant. Since the sludge contains a high volume of moisture, the liquid and solids fractions of the sample should be analysed separately. The full-spectrum analysis (U-238, U-235, Th-232 and their progeny) should be repeated annually, while the total uranium and thorium analysis should be repeated monthly.
- Full-spectrum analysis, including total uranium and thorium, of the treated water before released to the Blesbok Spruit. The full spectrum analysis (U-238, U-235, Th-232 and their progeny) should be repeated biannually, while the total uranium and thorium analysis should be repeated monthly.

No data is available for potential exposure to workers during maintenance activities at the Water Treatment Plant and the sludge disposal operations.

- It is recommended that radiation surveys (e.g., gamma dose rate and surface contamination) be performed during scheduled maintenance activities until it can be demonstrated with certainty that there is no contamination on equipment and components above the clearance levels for release of the material into the public domain.



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Appendix A: Radionuclide and Element Dependent Data

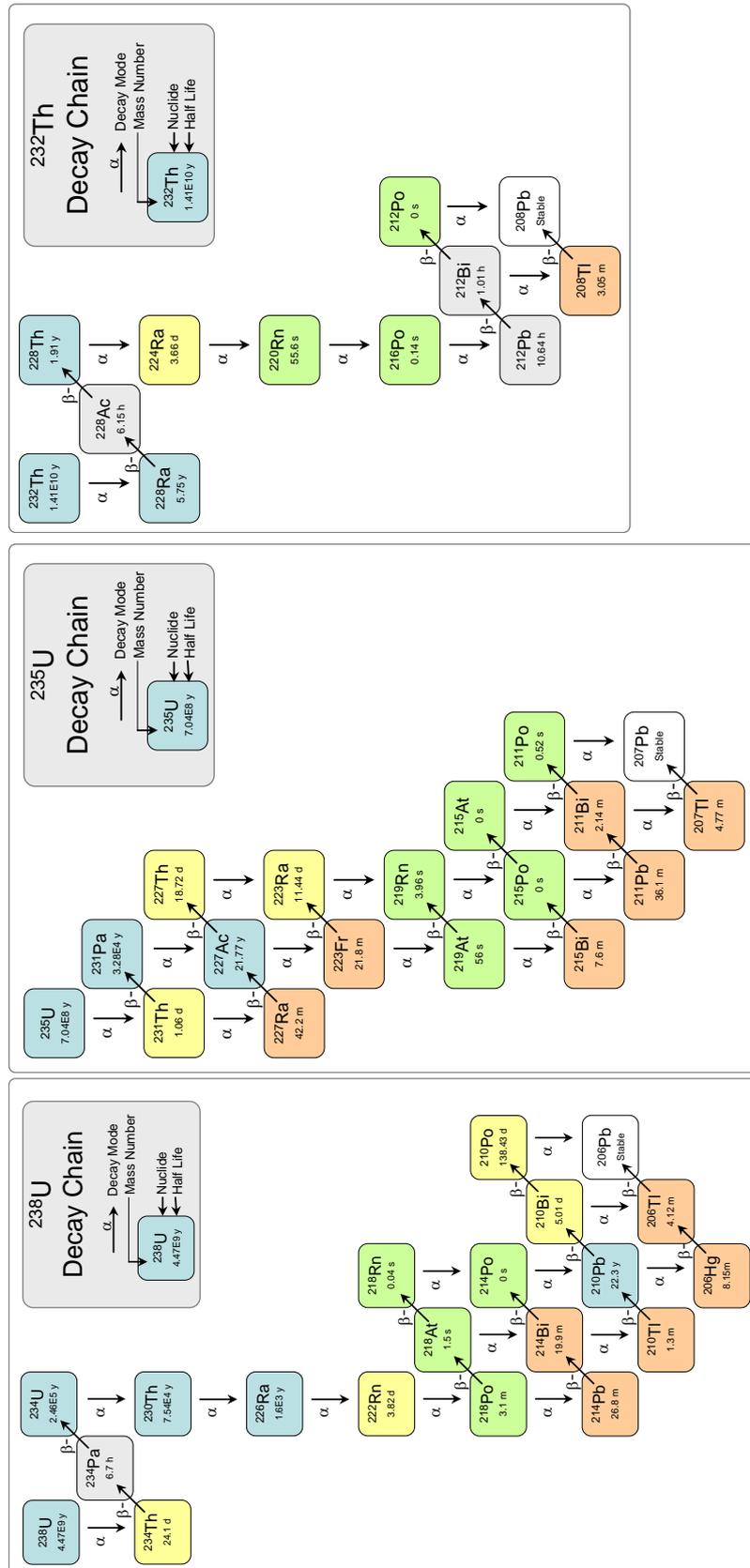


Figure A 1 Schematic illustrations of the U-238, U-235, and Th-232 decay chains.

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

Appendix B: Necsa Radioanalytical Laboratory Results

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Contact: **Mr I Kruger**
 Company: **ARCONSA**
 Address: **P O Box 34118**
Glenstantia
0010

Date: **2016-10-13**
 Report number: **RS2016-4006-01**
 Pages: **3**
 Order no.: **Arconsa-Necsa-001/2016**

Job number: **RS2016-4006-01** Page 2 of 3

1. SERVICE
 Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.
 Number of samples received: 1
 Date samples received: 2016-09-07

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2016-10-04	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2016-10-10	Q Daniels	E Nhlapo
WIN-124	Radium by alpha spectrometry	2016-10-13	A Mokgalane	C Zwane
WIN-145	Uranium by alpha spectrometry	2016-10-13	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2016-10-13	N Sono	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2016-10-13	T Kota	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.

3. RESULTS
 3.1 Results are attached as an appendix to this report.
 3.2 Reported results relate only to the sample portions tested.
 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE
 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
 4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.

 4.3 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
 4.4 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **N Sono**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

① Directors Dr KR Kemm (Chairperson), Dr NT Magau, Dr XH Mkhwanazi, Dr AS Tsela, Mr MPK Tshivhase, Mr N Ngcobo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosisa, Mr GP Tshelane (CEO)

② Company Secretary First Corporate Secretaries (Pty) Ltd

REG 2000/003735/06

Job number: **RS2016-4006-01** Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	Treated Water		
Lab Code	RS2016-4006X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	34.8	4.1	1.3
²³⁴ U	60.1	5.5	1.3
²³⁰ Th	29.0	6.5	22
²²⁶ Ra	25.4	3.9	1.6
²¹⁰ Po	9.06	3.24	3.2
²³⁵ U	1.60	0.19	0.061
²²⁷ Th	5.42	2.47	5.3
²²³ Ra	-0.65	1.4	1.8
²³² Th	3.98	1.78	2.2
²²⁸ Th	9.98	3.26	7.5
²²⁴ Ra	< MDA		5.7
Gross alpha	340	130	390
Gross beta	1320	140	380

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Contact: **Mr ID Kruger**
 Company: **ARCONSA**
 Address: **P O Box 34118**

Glenstantia
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Date: **10 November 2016**
 Report number: **RS2016-4005-01**
 Pages: **3**
 Your reference: **Arconsa-Necsa-001/2016**

Analysis Report

Radioactivity analysis of solids

Compiled by: **MJ Raven**

Checked by: **N Seaga**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

1. SERVICE

Analysis of solid samples for gross alpha and beta analysis and for selected radionuclides in the uranium and thorium decay series.
 Number of sample(s) received: 2
 The sample(s) were received on: 2016-09-07
 Purchase order received on: 2016-09-30

2. SAMPLE PREPARATION AND ANALYSIS

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry, mill and homogenise samples	2016-10-05	E Molhabane	O Mathekga
WIN-138	Gross alpha/beta analysis on solids	2016-10-13	S Zhou	E Nhlapo
WIN-167	Uranium/Thorium by neutron activation analysis	2016-11-03	A Sathekge	N Seaga
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma spectrometry	2016-11-03	R Gaven	A Sathekge
WIN-158	²¹⁰ Pb by low energy gamma spectrometry	2016-10-25	M Rapetsoa	A Sathekge

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Results report are related only to sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.
- 3.4 ²³⁴U activity was derived from the ²³⁸U activity, by using natural isotopic ratio

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.
 - Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
 - Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods.
 - The individual test reports are available upon request
- 4.3 The compiler is the Technical Expert for all the methods.
- 4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	Soil			Soil (Sludge)		
	Lab code	RS2016-4005X001		RS2016-4005X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	115	3	0.62	503	12	0.63
²³⁴ U	116	3	0.63	507	12	0.63
²²⁶ Ra	1180	40	59	538	31	59
²¹⁰ Pb	1820	110	270	< MDA		220
²³² U	5.29	0.14	0.029	23.1	0.5	0.029
²³² Th	18.3	1.1	1.6	< MDA		3.7
²²⁸ Ra	< MDA		120	76	26	77
²²⁸ Th	< MDA		170	< MDA		160
⁴⁰ K	760	118	300	300	110	330
Gross alpha	8020	1220	1900	2870	710	1300
Gross beta	2780	150	230	958	86	150

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

Notes:

- 1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
- 2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
- 3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
- 4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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RADIOACTIVITY ANALYSIS TEST REPORT

Quotation number	SOQ0000339	Purchase order number	ACS-000-P03-2024
Report number	JOB00002321-01	Report date	2025/01/31

1 Particulars of the customer

Customer name	Aquism Consulting (Pty) Ltd	Contact person	Dr. Japie van Blerk
Address	109 Bosduif Crescent Wierda Park 0157	Tel:	082 806 6159
		Email:	aquism@netactive.com

2 Sample Information

Sample descriptions	Sludge	Number of samples	01
Sample receipt date	2024/11/14		

3 Laboratory Environmental Conditions

Temperature	12 °C – 30 °C	Relative Humidity	0 – 80%
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4 Test Results

Sample Number: JOB00002321X001		Customer ID: ERB Sludge				
Service Code	Method	Accredited	Parameter	Units	Activity	Uncertainty
YRGI-0307	RA-QMS-WIN-0226	NO	U-238	Bq/kg	178	5
YRGI-0307	RA-QMS-WIN-0226	NO	U-234	Bq/kg	179	5
YRGI-0305	RA-QMS-WIN-0101	YES	Ra-226	Bq/kg	985	32
YRGI-0309	RA-QMS-WIN-0158	NO	Pb-210	Bq/kg	< 240	
YRGI-0307	RA-QMS-WIN-0226	NO	U-235	Bq/kg	8.19	0.23
YRGI-0307	RA-QMS-WIN-0226	NO	Th-232	Bq/kg	3.40	0.56
YRGI-0305	RA-QMS-WIN-0101	YES	Ra-228	Bq/kg	118	32
YRGI-0305	RA-QMS-WIN-0101	YES	Th-228	Bq/kg	< 78	
YRGI-0305	RA-QMS-WIN-0101	YES	K-40	Bq/kg	447	137

4.1 Explanatory notes

- A result with its associated uncertainty is reported only if it is greater than the minimum detectable activity (MDA) of the relevant test measurement, else the minimum detectable activity value will be reported with a less than symbol (<) in front of the value.
- Minimum detectable activity is reported with a confidence level of 95%. Measurement of uncertainty is reported with a coverage factor of k=1
- The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements.
- Results indicated in bold were obtained from methods that are not included in the SANAS schedule of Accreditation for this laboratory.

Job Card Number: JOB00002321
 Purchase Order Number: ACS-000-P03-2024

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Page 2 of 2

5 Date(s) of performance of laboratory activities

Method / Activity	Date completed	Analyst
RA-QMS-WIN-0114	2024-12-04	L Seshoka
RA-QMS-WIN-0226	2024-01-20	MA Satheke
RA-QMS-WIN-0101	2024-12-23	MA Satheke
RA-QMS-WIN-0158	2024-12-17	K Hotane
Report compilation	2025-01-31	MA Satheke

5.1 Explanatory notes

- The date of completion is the date on which the total number of samples have been completed by an activity or method.

6 OPINIONS AND INTERPRETATIONS

- None

7 Disclaimers

Results relate only to samples tested as received from client. Necsa are not liable for errors that are due to sampling and transport of samples by external parties. The results, opinions and/or interpretations expressed are based only on the samples received and tests performed. Opinions and interpretations are outside of the scope of SANAS accreditation. Results indicated in bold were obtained from methods that are not included in the SANAS schedule of Accreditation for this laboratory. Reports issued by NECSA shall not be reproduced, except in full, without the written approval of NECSA. Only the original version of this report, as kept by NECSA, shall be used in case of a dispute.

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 MA Satheke – Senior Technician

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 MMF Seaga – Section Head

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END OF REPORT

Job Card Number: JOB00002321
 Purchase Order Number: ACS-000-P03-2024

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RADIOACTIVITY ANALYSIS TEST REPORT

Quotation number	SOQ00000337	Purchase order number	ASC-000-PO3-2024
Report number	JOB00002320-01	Report date	2025/01/31

1 Particulars of the Customer

Customer name	AQUISIM CONSULTING (PTY) LTD	Contact person	Dr Japie Van Blerk
Address	109 BOSDUIF CRESCENT WIERDAPARK 0157	Tel:	082 806 6159
		Email:	aquisim@netactive.co.za

2 Sample Information

Sample descriptions	Liquid samples	Number of samples	04
Sample receipt date	2024/11/12		
Sampling date	Not Applicable		

3 Laboratory Environmental Conditions

Temperature	12 °C – 30 °C	Relative Humidity	0 – 80%
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4 Test Results

Service Code	Method	Accredited	Parameter	Units	Activity	Uncertainty
YRRC-0510	RA-QMS-WIN-0145	Yes	234U	mBq/L	596	46
YRRC-0510	RA-QMS-WIN-0145	Yes	235U	mBq/L	25.9	2.0
YRRC-0510	RA-QMS-WIN-0145	Yes	238U	mBq/L	563	44
YRRC-0511	RA-QMS-WIN-0142	Yes	227Th	mBq/L	<9.0	
YRRC-0511	RA-QMS-WIN-0142	Yes	228Th	mBq/L	<9.9	
YRRC-0511	RA-QMS-WIN-0142	Yes	230Th	mBq/L	30.1	6.4
YRRC-0511	RA-QMS-WIN-0142	Yes	232Th	mBq/L	<6.5	
YRRC-0506	RA-QMS-WIN-0124	Yes	223Ra	mBq/L	<11	
YRRC-0506	RA-QMS-WIN-0124	Yes	224Ra	mBq/L	<7.9	
YRRC-0506	RA-QMS-WIN-0124	Yes	226Ra	mBq/L	353	19
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross alpha	mBq/L	891	90
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross Beta	mBq/L	<850	

RadioAnalysis and Calibration Laboratory
 Job Card Number: [JOB00002320](#)
 Purchase Order Number: [ASC-000-PO3-2024](#)

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Sample ID: JOB00002320 X002		Customer ID: ERB Eff				
Service Code	Method	Accredited	Parameter	Units	Activity	Uncertainty
YRRC-0510	RA-QMS-WIN-0145	Yes	234U	mBq/L	516	45
YRRC-0510	RA-QMS-WIN-0145	Yes	235U	mBq/L	21.7	1.9
YRRC-0510	RA-QMS-WIN-0145	Yes	238U	mBq/L	472	42
YRRC-0511	RA-QMS-WIN-0142	Yes	227Th	mBq/L	<14	
YRRC-0511	RA-QMS-WIN-0142	Yes	228Th	mBq/L	<12	
YRRC-0511	RA-QMS-WIN-0142	Yes	230Th	mBq/L	50.4	10.1
YRRC-0511	RA-QMS-WIN-0142	Yes	232Th	mBq/L	9.07	3.14
YRRC-0506	RA-QMS-WIN-0124	Yes	223Ra	mBq/L	<11	
YRRC-0506	RA-QMS-WIN-0124	Yes	224Ra	mBq/L	<25	
YRRC-0506	RA-QMS-WIN-0124	Yes	226Ra	mBq/L	184	15
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross alpha	mBq/L	1010	120
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross Beta	mBq/L	1440	120

Sample ID: JOB00002320 X003		Customer ID: ESW-01				
Service Code	Method	Accredited	Parameter	Units	Activity	Uncertainty
YRRC-0510	RA-QMS-WIN-0145	Yes	234U	mBq/L	67.8	8.1
YRRC-0510	RA-QMS-WIN-0145	Yes	235U	mBq/L	1.39	0.25
YRRC-0510	RA-QMS-WIN-0145	Yes	238U	mBq/L	30.2	5.5
YRRC-0511	RA-QMS-WIN-0142	Yes	227Th	mBq/L	10.9	3.7
YRRC-0511	RA-QMS-WIN-0142	Yes	228Th	mBq/L	<11	
YRRC-0511	RA-QMS-WIN-0142	Yes	230Th	mBq/L	67.2	12.1
YRRC-0511	RA-QMS-WIN-0142	Yes	232Th	mBq/L	12.3	3.0
YRRC-0506	RA-QMS-WIN-0124	Yes	223Ra	mBq/L	<12	
YRRC-0506	RA-QMS-WIN-0124	Yes	224Ra	mBq/L	<18	
YRRC-0506	RA-QMS-WIN-0124	Yes	226Ra	mBq/L	<6.0	
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross alpha	mBq/L	243	39
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross Beta	mBq/L	956	90

RadioAnalysis and Calibration Laboratory
 Job Card Number: [JOB00002320](#)
 Purchase Order Number: [ASC-000-PO3-2024](#)

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Page 3 of 4

Sample ID: JOB00002320 X004 Customer ID: ESW-03

Service Code	Method	Accredited	Parameter	Units	Activity	Uncertainty
YRRC-0510	RA-QMS-WIN-0145	Yes	234U	mBq/L	321	24
YRRC-0510	RA-QMS-WIN-0145	Yes	235U	mBq/L	13.3	1.0
YRRC-0510	RA-QMS-WIN-0145	Yes	238U	mBq/L	289	22
YRRC-0511	RA-QMS-WIN-0142	Yes	227Th	mBq/L	<7.6	
YRRC-0511	RA-QMS-WIN-0142	Yes	228Th	mBq/L	<9.1	
YRRC-0511	RA-QMS-WIN-0142	Yes	230Th	mBq/L	34.7	7.1
YRRC-0511	RA-QMS-WIN-0142	Yes	232Th	mBq/L	10.3	2.6
YRRC-0506	RA-QMS-WIN-0124	Yes	223Ra	mBq/L	<10	
YRRC-0506	RA-QMS-WIN-0124	Yes	224Ra	mBq/L	<8.2	
YRRC-0506	RA-QMS-WIN-0124	Yes	226Ra	mBq/L	<9.0	
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross alpha	mBq/L	501	72
YRAB-0202	RA-QMS-WIN-0161	Yes	Gross Beta	mBq/L	1400	110

4.1 Explanatory notes

(a) A result with its associated uncertainty is reported only if it is greater than the minimum detectable activity (MDA) of the relevant test measurement, else the minimum detectable activity value will be reported with a less than symbol (<) in front of the value.

(b) Minimum detectable activity is reported with a confidence level of 95%. Measurement of uncertainty is reported with a coverage factor of k=1

(c) The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements.

(d) The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities.

(e) Results indicated in bold were obtained from methods that are not included in the SANAS schedule of Accreditation for this laboratory.

5 Date(s) of performance of laboratory activities

Method / Activity	Date completed	Analyst
RA-QMS-WIN-0121: Filtration of suspended solids	2024-12-13	HO Mathekga
RA-QMS-WIN-0161: Gross alpha/beta-analysis	2025-01-29	NN Lebepe
RA-QMS-WIN-0124: Radium by alpha spectrometry	2025-01-30	N Yawa/MA Mokgalane
RA-QMS-WIN-0145: Uranium by alpha spectrometry	2025-01-30	NN Lebepe
RA-QMS-WIN-0142: Thorium by alpha spectrometry	2025-01-30	TM Mokatse
Report Compilation	2025-01-31	NN Lebepe

5.1 Explanatory notes

(a) The date of completion is the date on which the total number of samples have been completed by an activity or method.

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Page 4 of 4

6 Opinions and Interpretations

(a) None

7 Disclaimers

Results relate only to samples tested as received from client. NECSA is not liable for errors that are due to sampling and transporting of samples by external parties. The results, opinions and/or interpretations expressed are based only on the samples received and tests performed. Opinions and interpretations are outside of the scope of SANAS accreditation. Reports issued by NECSA shall not be reproduced, except in full, without the written approval of NECSA. Only the original version of this report, as kept by NECSA, shall be used in case of a dispute.

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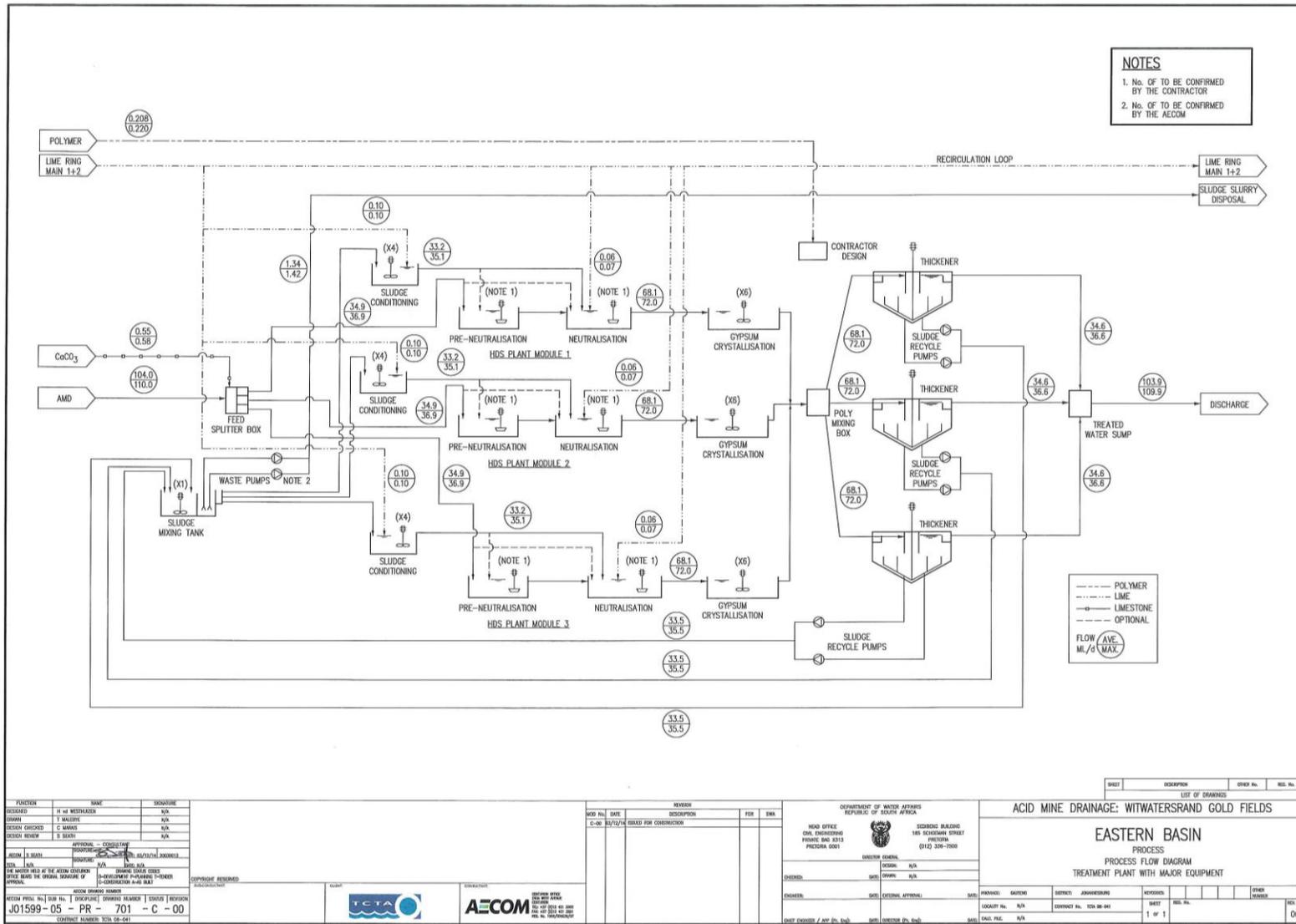


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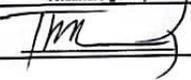
Job Card Number: **JOB00002320**

Purchase Order Number: **ASC-000-PO3-2024**

Appendix C:
Process Flow Diagram for the DWS Eastern Basin Water
Treatment Plant



Appendix D:
Calibration Certificates used for the Contamination and Dose
Rate Survey at the DWS Eastern Basin Water Treatment Plant

Calibration Certificate		Certificate No : CQ-KVG-24/9389		Page 1 of 3	
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Job card details					
Question Number : SOQ0000430-1		Purchase Order Number : CASH			
Job Card Number : JOB0001874					
1. Particulars of the customer			Instrument details		
Customer Name : MJC Radiological and Environmental Services			Manufacturer : Thermo Scientific		
Address : Casa Uvengo 106, Lillierona Boulevard, Uvongo KZN, 4270			Instrument Make : RadEye G-10 Gamma Survey Meter		
Contact Person : Gcimumazi Sibanyoni			Instrument Ser No : 0575		
			Calibration Range : From: 2,0 µSv/h to 10,0 mSv/h		
			MTE Number : 0575		
1.1. Details of the Calibrated Instrument					
Date of Receipt : 18-Oct-24		Expiry Date : Jan-26		(Week 1)	
Date of Calibration : 02-Nov-24		Date of Issued Certificate : 02-Nov-24			
2. Details of the calibration					
2.1. Environmental conditions		Temperature : 24.2 °C (Allowable limits (20 °C ± 5 °C))	Atmospheric Pressure : 872.1 mBar (700 to 900) mBar	Relative Humidity : 35.8 % (10 to 90) %RH	
2.2. Calibration procedure		CAL-QMS-WIN-0027 Calibration Spreadsheet : RadEye G-10 Gamma Survey Meter			
3. Calibration procedure					
3.1. The instrument was calibrated for gamma radiation from ¹³⁷ Cs. The instrument was positioned, with the shutter closed, (where applicable) in the radiation beam with the axis of the probe normal to the beam axis.					
3.2. In order to evaluate the instrument's response to variation in radiation energy it was also exposed to radiation from ²⁴¹ Am.					
3.3. The effective point of measurement was taken at a point at the center of the cross marked at back of the instrument.					
3.4. The pre-calibration checks were satisfactory and there was no visible damage. And there were no batteries in the instrument.					
4. Instrument background reading					
The instrument reading in a low background area was <0.25 µSv/h The instrument background reading was 0.13888888888889 µSv/h					
		Calibration Laboratory ISO 17025:2017			
Calibrated by: B Ramaphakela	Checked by: T.M. Ramashidzha	Approved by: E.N. Moalosi			
Metrologist	Technical Signatory	Laboratory Manager			
					

Calibration Certificate		Certificate No : CQ-KVG-24/9389		Page 2 of 3	
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5. Variation of response to radiation energy					
For Am-241 the instrument reads high by a factor 1,706 and is not suitable for measuring X- or gamma ray energies below 60keV. An acceptable response factor is between 0.67 and 1.5					
6. Results of the energy response factor					
True Ambient Dose Equivalent Rate µSv/h		Instrument readings µSv/h		factor	
²⁴¹ Am	¹³⁷ Cs	²⁴¹ Am	¹³⁷ Cs	1,763	
50,070	50,038	90,91	51,54		
Scales used for measurements		10 - 100 µSv/h		10 - 100 µSv/h	
The energy response factor is calculated by means of the instrument's readings for ²⁴¹ Am and ¹³⁷ Cs when exposed to the indicated exposure rates as follows:					
Factor = $\frac{\text{Instrument reading for Am}}{\text{Instrument reading for Cs}} \times \frac{\text{True Cs exposure rate}}{\text{True Am exposure rate}}$					
8. Results					
Scale	Instrument reading before adjustment µSv/h	Instrument reading after adjustment µSv/h	True Ambient Dose Equivalent Rate µSv/h	% Deviation from true exposure rate (%)	Uncertainty of Measurements (%)
0 - 10 µSv/h	2,17	2,17	2,00	8,44	16
	5,28	5,28	5,00	5,53	16
	8,31	8,31	8,00	3,81	16
10 - 100 µSv/h	20,95	20,95	20,03	4,59	12
	51,54	51,54	50,04	3,00	12
	81,55	81,55	80,13	1,77	12
100 - 1000 µSv/h	206,60	206,60	200,46	3,06	12
	514,20	514,20	500,56	2,72	12
	828,30	828,30	801,83	3,30	12
Scale	Instrument reading before adjustment µSv/h	Instrument reading after adjustment µSv/h	True Ambient Dose Equivalent Rate µSv/h	% Deviation from true exposure rate (%)	Uncertainty of Measurements (%)
1 - 10 mSv/h	2,06	2,06	2,00	2,93	12
	5,14	5,14	5,00	2,72	12
	8,20	8,20	8,01	2,46	12
Average deviation from true exposure rates:				3,69	
		Calibration Laboratory ISO 17025:2017			
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Calibration Certificate Certificate No : CQ-KVG-24/9389 Page 3 of 3

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* % Deviation from the true exposure rate is defined by:

$$\% \text{ Deviation} = \left[\frac{\text{Measured exposure rate} - \text{True exposure rate}}{\text{True exposure rate}} \right] \times 100$$

9. Acceptable deviations
 Individual deviations must be within $\pm 25\%$ and the average deviation within $\pm 15\%$.

10. Uncertainty of measurements
 The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$ providing a level of confidence of approximately 95%, the uncertainty of measurement has been estimated in accordance with the principles defined in the JCGM GUM-6: 2020, Guide of Uncertainty of Measurement, ISO, Geneva, 2020

11. Traceability
 The measurements results are traceable to the National Measurements Standard for air Kerma.

12. Check source measurements
 No check source was supplied

13. Disclaimers
13.1. Validity of Calibration
 The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. It is recommended that recalibration be undertaken at an interval that will ensure that the instrument remains within the desired limits. This certificate may not be reproduced other than in full without written approval of the issuing laboratory. The reported results relate only to the items calibrated.

13.2. Recognition of the certificates
 The South African National Accreditation System (SANAS) is a member of the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition (MRA). This arrangement allows for the mutual recognition of calibration data by member accreditation bodies worldwide.

13.3. Explanatory Notes
Calibration frequency
 In the Republic of South Africa in accordance to hazardous substance act 15 of 1973 (updated 26 February 1993) the expiry date is 7 months after the date of calibration for radiography and 14 months after the date of calibration for general use. In other countries this may be different and it is the responsibility of the user to ascertain legal requirements of the country where the instrument is used.

—end of calibration certificate—

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Job Card Details
 Quotation Number : SOQ0000430-1 Purchase Order Number : CASH
 Job Card Number : JOB00001874

1. Particulars of the customer	Instrument Details
Customer name : MJC Radiological and Environmental Services	Manufacturer : Thermo Scientific
Address : Casa Uvongo 106, Lilliecrona Boulevard, Uvongo KZN, 4270	Instrument Make : RadEye SX Serial Number : 51475
Contact Person : Gcinumuzi Sibanyoni	Calibration Range : Up to 7.5 kBq
Calibration of : RadEye SX with a Dual Scintillation Probe DP2R-4A	MTE Number : 51475.11332 Probe Serial No : 11332

2. Calibration Dates and Frequency
 Date of Issue : 02 November 2024 Expiry Date : Jan 2026 (week 1)
 Date of Receipt : 18 October 2024 Calibration Frequency : 14 Months
 Date of Calibration : 02 November 2024

3. Calibration Information			
3.1. Environmental condition	Temperature	Atmospheric Pressure	Relative Humidity
Contamination Laboratory	24,6°C	875.4 mBar	42 %
Calibration track room	24,4°C	875.4 mBar	34,5 %
3.2. Calibration procedure : CAL-QMS-WIN-0030			
3.3. Calibration spreadsheet : RadEye SX			

4. Instrument setup
 4.1. The instrument parameters were set as follows:

Parameter	Setting Before	Setting After
High voltage setting	780 V	860 V
Threshold C1 (Gross value)	40 mV	40 mV
Threshold C2	2150 mV	2150 mV
Threshold C3 (Alpha)	2200 mV	2200 mV
Threshold C4	2220 mV	2220 mV
Units	Bq/cm ²	Bq/cm ²
Overload countrate	50000 cps	50000 cps
Overload current	40µA	40 µA
Deadtime C1	6 µs	6 µs
Deadtime C2	6 µs	6 µs
Deadtime C3	6 µs	6 µs
Deadtime C4	6 µs	6 µs
Time Out	100 s	100 s
Sigma Factor	6	6
Phase Fade out	ON	ON
Window	R1-R2;R3	R1-R2;R3

	sanas Calibration Laboratory ISO 17025:2017	Calibration Laboratory ISO 17025:2017
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Calibration Certificate Certificate No : CQ-KVG-24/9388 Page 2 of 3

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4.2. The high voltage was determined as described in the instrument manual.
4.3. The optimum value was found to be 860 V and the calibration was carried out at this setting.
4.4. The pre-calibration checks were satisfactory, e.g. there was no visible damage, and the instrument settings were checked, and the batteries were not in good condition.

5. Background during calibration

		Background during calibration	
5.1. Alpha background	: 0,01 cps	Alpha background	: 0,008 Bq/cm ²
5.2. Beta Background	: 21,8 cps	Beta Background	: 2,164 Bq/cm ²

6. Calibration constants

6.1. The response to 100 mm x 100 mm certified extended area sources was determined for two beta emitting nuclides and one alpha emitting nuclide.
6.2. The detector (without the plastic cap and metal shield) was positioned over the source with its front face parallel to the source and 4mm from the source.
6.3. The results are summarized in the table below.

Nuclide	Maximum Energy MeV	Instrument function	Net counts per		Uncertainty of Measurements %	%E2 π	PAR Percentage Activity Response
			3.7 Bq/cm ²	0.37 Bq/cm ²			
⁹⁰ Sr/ ⁹⁰ Y	2,27	β	35,67	-	14	29,62	19,68
⁵⁴ Co	0,71	β	29,18	-	14	26,64	16,10
²⁴¹ Am	5,54	α	-	2,26	14	27,70	12,47

Notes:

- The instrument response for ¹⁴C is negligible.
- The instrument response in net cps (excluding background) to a beta contamination level of 3.7 Bq/cm² is given in column 4. Two efficiencies are given for the two given energies. The user of the instrument must select the appropriate response factor. This will be determined by the energy closest to that of the contamination under investigation.
- The instrument's response in net counts per second (excluding background) to an alpha level of 0.37 Bq/cm² is given in column 5.
- %E2 π refers to the efficiency of the detection of particles emitted from the surface of the source towards the detector.
- PAR is the percentage surface activity response and can be used to calculate surface contamination as follows:

$$\text{Surface activity (Bq/cm}^2\text{)} = \left[\frac{\text{Measured count rate} - \text{background count rate}}{\text{Probe area (cm}^2\text{)} \times \text{PAR}} \right] \times 100$$

NOTE: The effective probe area is 49 cm²

sanas Calibration Laboratory 1203		
Calibrated by: B Ramaphakela Metrologist	Checked by: T.M Ramashidzha Technical Signatory	Approved by: E.N Mososi Laboratory Manager

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6. Linearity response check

6.1. The instrument's response to known exposure rates from ¹³⁷Cs radiation (with the detector shield in place) was 649 cps per 1 mR h (10 μ Sv h)
6.2. The instrument's average deviation from linearity was -2.6 cps between 50 and 3500 cps.

7. Rejection Factor

7.1. Alpha rejection factor for a beta source : 0,000421408
7.2. Beta rejection factor for an alpha source : 0,12
Acceptable rejection factors are:
Alpha rejection factor : $\leq 0,01$
Beta rejection factor : $\leq 0,30$

8. Check source measurement
No check source was supplied

9. Uncertainties of measurements
The uncertainties of measurement were estimated not to exceed 14%.
The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2 providing a level of confidence of approximately 95 %, the uncertainty of measurement has been estimated in accordance with the principles defined in the JCGM GUM 6: 2020, Guide of Uncertainty of Measurement, ISO, Geneva, 2020

10. Measurements Traceability
The calibration is traceable to the national measuring standards for Surface Emission Rate and Air Kerma.

11. Disclaimers

11.1. Recognition of the certificates
The South African National Accreditation System (SANAS) is a member of the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition (MRA). This arrangement allows for the mutual recognition of calibration data by member accreditation bodies worldwide.

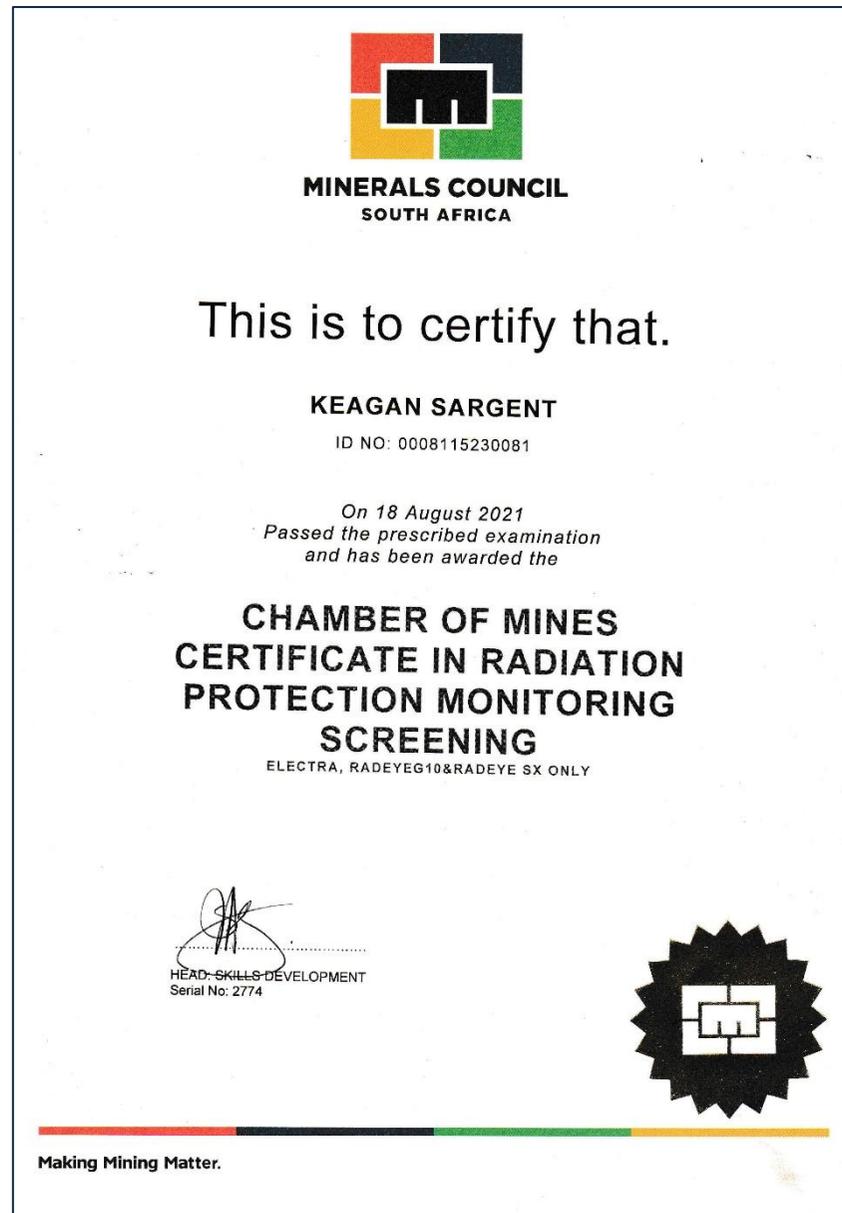
11.2. Validity of Calibration
The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. It is recommended that recalibration be undertaken at an interval that will ensure that the instrument remains within the desired limits. This certificate may not be reproduced other than in full without written approval of the issuing laboratory. The reported results relate only to the items calibrated.

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Appendix E:
East Rand Basin Numerical Groundwater Model for the Waste
Disposal Flow and Advective Transport Evaluation (Artesium,
2024b)



East Rand Basin Numerical Groundwater Model for the Waste Disposal Flow and Advective Transport Evaluation

**ERB Numerical Groundwater Transport Model and Risk
Quantification at Grootvlei #3 and Grootvlei #4 Shafts**

Technical Report

Project no: 2024-086

Prepared for: ID Kruger Consulting cc

13 March 2025

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East Rand Basin Numerical Groundwater Model for the Waste Disposal Flow and Advective Transport Evaluation

ERB Numerical Groundwater Transport Model and Risk Quantification at Grootvlei #3 and Grootvlei #4 Shafts

Technical Report

13 March 2025

Conducted on Behalf of:

ID Kruger Consulting cc

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Hydrogeologists & Mine Water Solutions

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DOCUMENT HISTORY

Report no	Date	Version	Status
2024-086	13 March 2025	1	Final

LIST OF ABBREVIATIONS

Abbreviation	Description
a	Annum
BDL	Below detection limit
DWAF	Department of Water Affairs and Forestry
GW	Groundwater
ha	hectare
mamsl	metres above mean sea level
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbgl	metres below ground level
Mon	Month/s
P5	5 th Percentile (Lower range)
P50	50 th Percentile (Median)
P95	95 th Percentile (Upper range)
SANS	South African National Standards
SW	Surface Water
TDS	Total Dissolved Solids

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1 INTRODUCTION

Artesium Consulting Services (Pty) Ltd (referred to as ACS) was appointed by ID Kruger Consulting cc and Aquisim Consulting Pty (Ltd), referred to as the Client, to quantify the risk associated with waste disposal in the East Rand Basin (ERB). The ERB (referred to as the site) outcrops to the south-east of Johannesburg and encompasses an area of approximately 720 km². This investigation focused on modelling the advective flow dynamics within the Grootvlei sub-basin, as a results of injection of sludge into Grootvlei #4 shaft and abstraction of groundwater from Grootvlei #3 shaft. Interpreting the simulated mass tracer plume injected into the mine void workings helped characterise the flow characteristics and pathways from the source and possible receptors within the East Rand Basin watershed.

1.1 Objectives

The project objective is to:

- Update the existing numerical groundwater model (AGES, 2006 and Exigo, 2017) by incorporating monitoring data to develop a numerical groundwater transport model to quantify the long-term advective and reactive impacts associated with waste sludge injection/disposal at the Grootvlei #4 Shaft.

1.2 Scope of Work

The scope of work and project timeline is tabulated (Table 1-1) below:

Table 1-1: Summary of the Scope of Work

Scope of Work		Date Completed
1	Sampling & Delivery to Necsa Lab	
1.1	Sampling of sludge and water	Sept-2024
1.2	Submission of sample to Necsa	Nov-2024
2	Necsa Radioanalysis	
2.1	Submission to of samples to Necsa	Nov-2024
2.2	Radioanalysis of samples	Current
3	Analysis and evaluation of monitoring data - 3D Numerical Groundwater Flow & Chemical Mass Transport Models	
3.1	Analysis and evaluation of the groundwater and abstraction monitoring data to be use for model recalibration	Jan-2025
3.2	Update of the conceptual groundwater models with latest data to include updated surface water and groundwater interactions	Jan-2025
3.3	Update of the 3D geometric numerical groundwater flow model (Feflow) based on the monitoring data	Jan-2025
3.4	Recalibration of the groundwater flow model with monitoring data	Feb-2025
3.5	Develop 3D chemical mass tracer transport model	Feb-2025
3.6	Simulation of flow and mass (advective & reactive) scenarios for long-term impact analysis	Feb-2025
3.7	Compilation of GIS maps	Feb-2025
3.8	Compilation of a technical groundwater flow and tracer transport modelling report	Feb-2025

Scope of Work		Date Completed
4	Update of NNR Submission Report	
4.1	Incorporate groundwater modelling results	Pending
4.2	Interpret Necsra radioanalysis results	Pending
4.3	Update report	Pending
4.4	Comment period	Pending
4.5	Finalise report	Pending
5	Submission to NNR	

2 DESCRIPTION OF THE STUDY AREA

2.1 Site Overview

The East Rand Basin (ERB) mining area has been extensively mined since 1886 up to depths of approximately 3.5 km. During active mining the ERB was dewatered (purged) to allow for mining operations to continue. Dewatering was ceased as mines reached their end of life and as a result dewatering rates increased in the remaining operational mines. Until 1991 the bulk of the dewatering from the ERB was conducted from Sallies #1 Shaft with smaller volumes being pumped from the Grootvlei #3 and #4 shafts. Currently, approximately 71 Ml/d of water is abstracted at the Grootvlei #3 shaft. On average 1 614 m³/d of sludge is disposed at the Grootvlei #4 shaft situated approximately 2.2 km (refer to Figure 2-2) to the north-west of Grootvlei #3. The rest of the abstracted water is discharged into the Blesbokspruit. It is assumed the sludge is disposed down the #4 shaft at a depth of 700 mbgl (meters below ground level) via gravity and due to the density (1.4 kg/l), settles at the bottom of the shaft mine void workings. The interaction between the disposal of sludge and abstraction of water from the ERB on the surrounding environment was the focus of this investigation.

2.2 Local Climate

Rainfall data is recorded at the ERB plant (refer to Figure 2-2) and stretched from February 2013 to November 2024. The statistical analysis of the 11 year and 10 month long rainfall record is displayed in Figure 2-1. The Mean Annual Precipitation (MAP) was calculated at 641 mm/a.

Table 2-1: ERB Plant Monthly Recorded Rainfall Statistical Distribution

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
P99	203	170	178	121	55	20	14	3	21	110	225	236	904
P98	199	168	171	119	53	19	13	3	20	108	223	232	893
P95	186	163	151	112	45	17	11	2	15	101	217	220	860
P90	166	154	121	102	34	14	8	1	8	90	208	200	814
P50	111	68	41	46	5	2	0	0	3	42	110	134	641
Average	108	83	66	55	14	5	2	0	5	47	121	140	622
P05	40	11	27	13	0	0	0	0	0	10	58	69	386

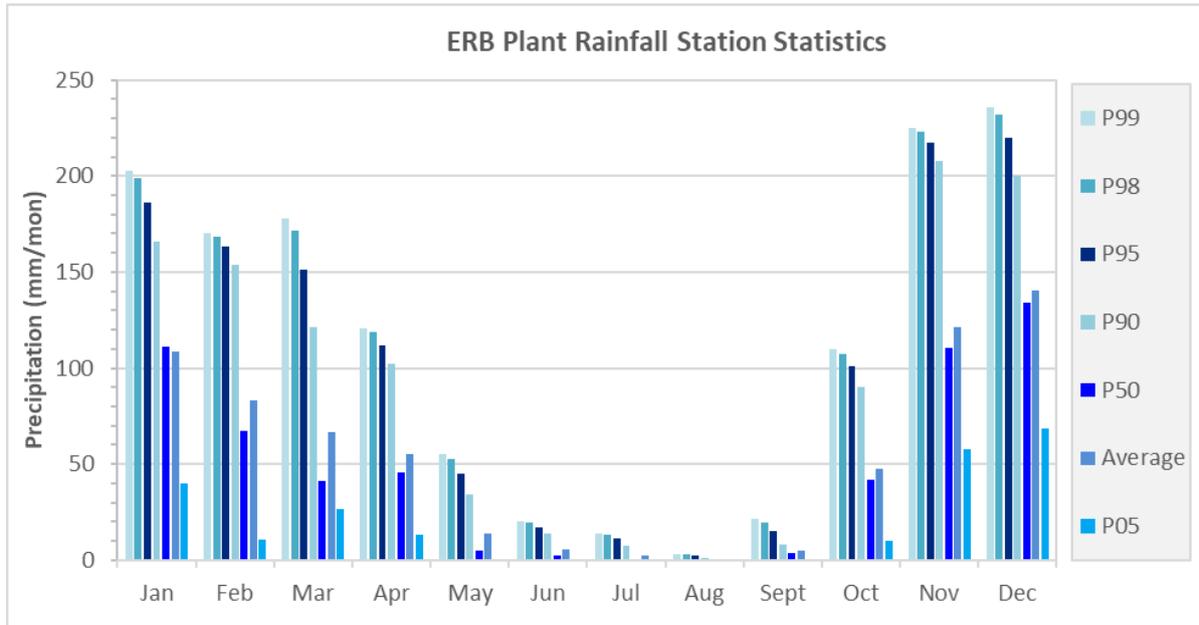


Figure 2-1: Statistical Monthly Distribution for Rainfall Data Recorded at the ERB Plant

2.3 Topography and Drainage

The topography data for the model boundary was derived from the 2628BC, 2628CB, and 2628DA 1:50 000 topographical map sheets (NGI, 2024). The topographical map in Figure 2-3 displays that the Grootvlei #4 Disposal shaft is situated at approximately 1 580 mamsl with the area sloping towards the south-east and towards Grootvlei #3 Abstraction Shaft. The Blesbokspruit drains the area to the east of the ERB plant. The Blesbokspruit River flows from north to south across the model boundary and drains the area to the east of the plant. Regionally, the area slopes from the high-lying (>1 650 mamsl) model boundary towards the two main catchment exit points situated at approximately 1 510 mamsl) in the south-west.

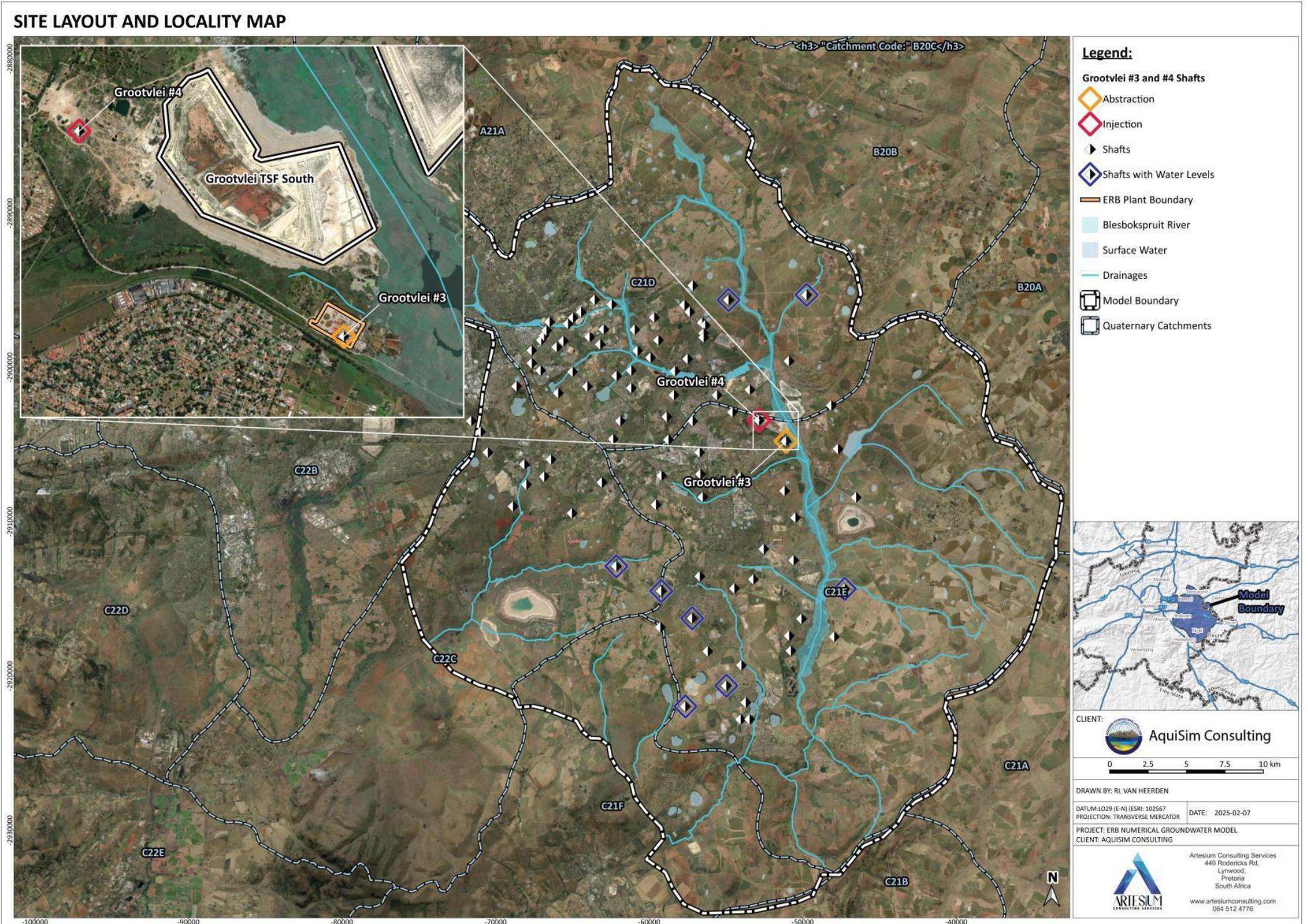


Figure 2-2: Site Layout and Locality Map

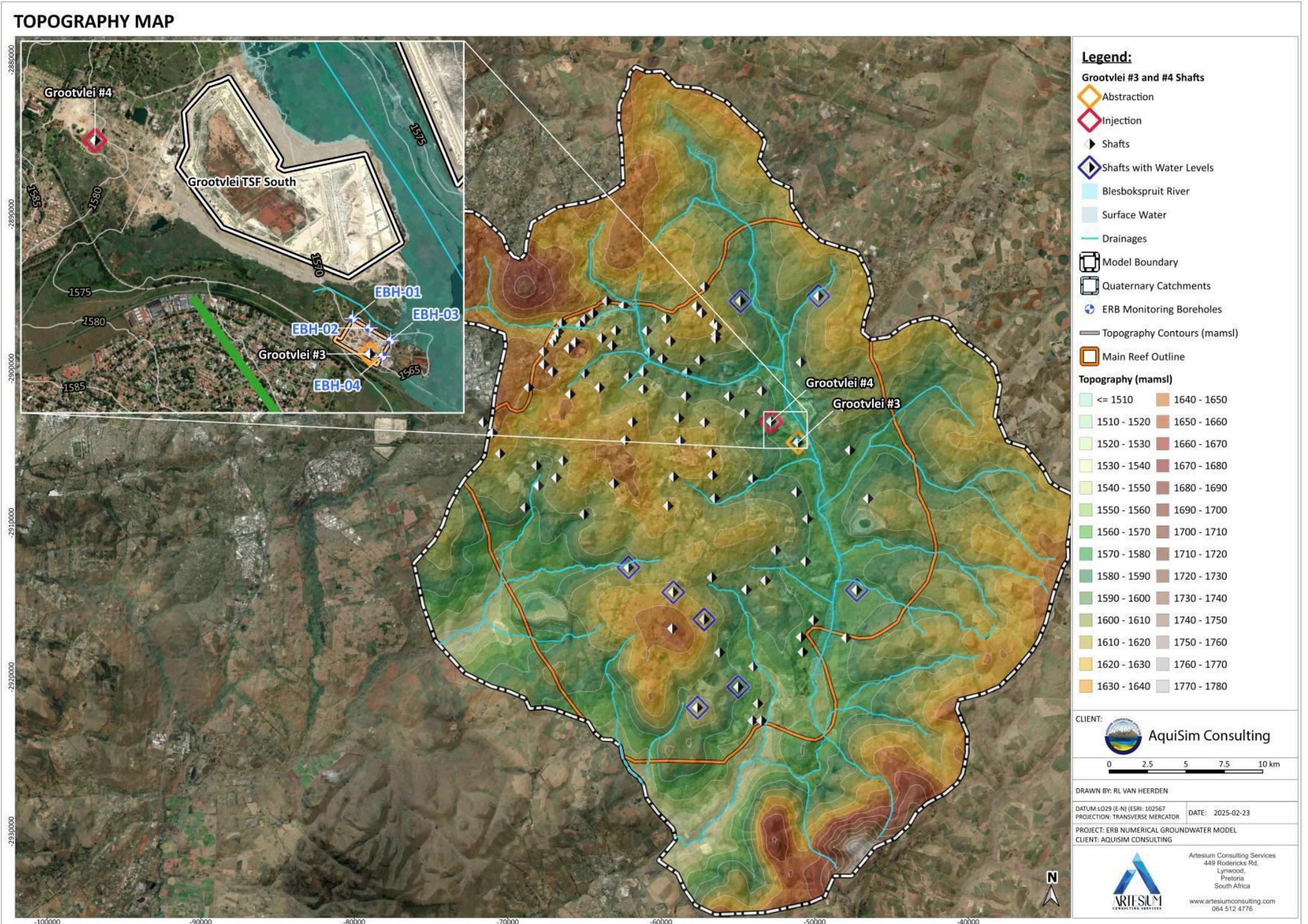


Figure 2-3: Topography Map