Environmental Impact Assessment for Sibanye Gold Limited's West Rand Tailings Retreatment Project

Radiological Impact Assessment Report

Project Number:

GOL2376

Prepared for:

Sibanye Gold Limited

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Digby Wells and Associates (South Africa) (Pty) Ltd
(Subsidiary of Digby Wells & Associates (Pty) Ltd). Co. Reg. No. 2010/008577/07. Fern Isle, Section 10, 359 Pretoria Ave Randburg Private Bag X10046, Randburg, 2125, South Africa
Tel: +27 11 789 9495, Fax: +27 11 789 9498, info@digbywells.com, www.digbywells.com

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Name	Responsibility	Signature	Date
Japie van Blerk	Compiler		30 September 2015

AquiSim Consulting (Pty) Ltd
Contact person: Japie van Blerk

109 Bosduif Crescent

Wierda Park

Centurion

0157

Tel: 012 654 0212

Fax: 086 689 6006

E-mail: aquisim@netactive.co.za

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Full name:	Jacobus Josia van Blerk
Title/ Position:	Director (AquiSim Consulting Pty Ltd)
Qualification(s):	Ph.D.
Experience (years):	25
Registration(s):	Pr.Sci.Nat. (RPS)

EXECUTIVE SUMMARY

The treatment of historical tailings in the West Rand area has a long history with Gold Fields, Rand Uranium, Harmony Gold Mining Company Limited (Harmony), Gold One and SGL completing a number of parallel, independent studies relating to the treatment of these historical tailings.

In late 2009 Gold Fields and Rand Uranium met to evaluate the potential synergy of an integrated flow sheet for the Cooke Uranium Project (Rand Uranium) and the West Wits Tailings Treatment Project (Gold Fields), both of which were nearing feasibility completion. The integration of the projects was also based on competent authority and I&AP requests to consolidate the two projects. A significant amount of re-engineering and confirmatory test work would have been required to achieve this and, given the momentum of the respective projects, it was agreed that the investment would not be justified at that point in time. After the completion of the respective projects they were put on hold because of economic circumstances at the time. Due to changes in ownership and economic forecasts the consolidation of these projects into what is now known as the West Rand Tailings Retreatment Project (WRTRP), is again viable.

Naturally occurring radionuclides originally associated with the gold bearing reefs of the Witwatersrand, are present in the tailings material associated with historical Tailings Storage Facilities (TSFs) that will be processed at the Central Processing Plant (CPP), and ultimately those tailings material that will be deposited at the regional TSF (RTSF) as part of the WRTRP. The presence of these naturally occurring radionuclides have the potential to impact negatively on the health of human beings if they undergo exposure. The protection of human health and the environment from adverse effects associated with exposure to ionizing radiation is regulated in terms of the National Nuclear Regulator Act (NNRA) (Act 47 of 1999) and the Nuclear Energy Act (NEA) (Act No. 46 of 1999), with the National Nuclear Regulator (NNR) as the regulating body.

The aim of this study is to present the radiological impact assessment of the WRTRP in a comprehensive, systematic and transparent manner, as input into the environmental authorisation process. The radiological public safety assessments (RPSAs) prepared as part of the Authorisation Change Request (ACR) to be submitted to the NNR were used as basis and input into the study. To ensure that the radiological impact assessment is conducted in a robust, but systematic and transparent manner, the following serves as specific objectives for the study:

- To define in broad terms, the nuclear regulatory framework for the radiological impact assessment process in accordance international recommendations and guidance, as well as national legislation and supporting regulations.
- To provide a description of the WRTRP, as well as the environmental and radiological baseline conditions in sufficient detail to facilitate a source-pathway-receptor analysis as basis to define and justify a discrete set of public exposure conditions as part of the radiological impact assessment process.

- To assess and analyse the radiological consequences of each public exposure condition for the different components of the WRTRP.
- To assess the significance of the radiological impact in terms of predefined impact assessment criteria; and
- To define mitigation measures, including public radiation protection measures, required to reduce the radiological impact to members of the public to be in compliance with the nuclear regulatory framework.

The approach followed was to assess the radiological consequences of each exposure condition in terms of a total effective dose criterion, and use the outcome of this process as qualitative criteria to assess the significance of the radiological impact of the WRTRP as required for the EIA process. Mitigation measures were proposed to reduce negative radiological impacts, or to improve positive impacts where appropriate and justified. It also includes the definition of a monitoring programme for inclusion in the Environmental Management Programme (EMP) and public Radiation Protection Programme (RPP).

With the dose assessment for the different components and facilities associated with the WRTRP as basis, the radiological impact assessment ratings were determined. It was concluded that most activities and facilities have a **Low to Medium Low (Negative)** rating during the operational and post-operational phases. Radiological material is not handled during the construction phase, and therefore the radiological impact is not of concern. The exception is the reclamation of the historical TSFs, which resulted in a **Moderate (Positive)** impact rating, mainly because of the positive contribution to the total effective dose if the sources (TSFs) are removed.

It was concluded that remedial actions as part of the EMP and public RPP are generally not required to reduce the radiological impact. The exception is the RTSF, which may include the application of a covering layer as part of the revegetation processes, which will by implication reduce the radon exhalation rate and thus the radon inhalation dose. However, this measure did not influence the impact rating. Most of the mitigation measures proposed as part of the air quality or groundwater impact assessment studies will have an indirect influence on the radiological impact, resulting in a potential decrease in the total effective dose. Several additional management actions were proposed for inclusion in the EMP and RPP. The proposed monitoring programme focused on source characterisation once the WRTRP is operational, as well as environmental monitoring of various environmental media.

From a radiological impact perspective, both in terms of the total effective dose calculations and the associated impact assessment ratings, the WRTRP can proceed as proposed.

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1 Introduction

There is a long history of gold and uranium mining in the broader West Rand area, with an estimated 1.3 billion tonnes of surface tailings containing in excess of 170 million pounds of uranium and 11 million ounces of gold. Sibanye Gold Limited (SGL) currently owns the majority of the tonnage and thus its gold and uranium content. SGL plans ultimately to exploit these resources and to develop a strong, long life and high yield surface business.

The West Rand Tailings Retreatment Project (WRTRP) is key to the successful execution of this development strategy. The WRTRP concept is well understood, with an 8 year history of extensive metallurgical test work, feasibility studies and design by a number of major mining houses. A pre-feasibility study (PFS) for the WRTRP completed during 2013 has confirmed that there is a significant opportunity to extract value from the SGL surface resources in a cost effective sequence.

A phased approach is envisaged for the implementation of the WRTRP. The ultimate WRTRP involves the construction of a large-scale Central Processing Plant (CPP) for the recovery of gold, uranium and sulfur from the available resources. The CPP, centrally located to the West Rand resources, will eventually treat up to 4 Mt per month of tailings inclusive of current underground arisings. The resultant tailings will be deposited on a modern tailings storage facility (TSF) referred to as the regional TSF (RTSF). The following benefits are envisaged following the implementation of the WRTRP (Digby Wells Environmental, 2015a):

- Investment of about R9 billion into the economy of the West Rand District Municipality;
- Significant job creation, with an estimated 2 000 temporary opportunities during the construction phase, and an estimated 500 sustainable employment opportunities once the project is operational;
- Protection of sensitive dolomitic aquifers and water resources through the removal of the historical TSFs, currently located on the dolomites, and the deposition of the reclaimed and reprocessed tailings onto the RTSF, to be constructed on impermeable bedrock, away from sensitive dolomitic areas.
- Removal of impacts associated with existing historical TSFs by reducing sulfur and uranium concentrations. The reduction in sulfur concentrations will in turn lower the risk of Acid Mine Drainage (AMD);
- Reduction of health risks to surrounding communities by addressing persistent dust fallout from historical TSFs spread over a vast area, into a single well-managed best practice designed RTSF.
- Release of valuable land that can be rezoned for residential, recreational, commercial, and agricultural use, as appropriate.

- Treatment of currently impacted water with the proposed Advance Water Treatment Facility (AWTF), which could potentially provide potable water for domestic and agricultural users, and thereby mitigating existing shortages.

1.1 Background radiation

Many radioactive isotopes (or radionuclides) occur naturally throughout the Earth's crust and are present in rocks, soils, river water, as well as in seawater. Most of these naturally occurring radionuclides, which are also associated with the gold bearing reefs of the Witwatersrand, are members of three radioactive series identified as the uranium (U-238), actinium (U-235), and thorium (Th-232) series, named according to the radionuclides that serve as progenitor (or parent) to the series products. In undisturbed environmental conditions, these radionuclides form part of the natural background radiation, to which all humans are exposed on a daily basis through the air they breathe, water they drink, soil they live and work on, as well as the food they eat (Kathren, 1998).

Practices that exploit the earth's resources may enhance the potential for human exposure to naturally occurring radionuclides by way of their products, by-products, residues and wastes. Industries such as mining and mineral processing operations and their associated facilities and activities have the potential to alter the natural background radiation by:

- Moving naturally occurring radionuclides from inaccessible locations to locations where humans can be exposed;
- Concentration of radionuclides in the accessible environment; or
- Changing the chemical or physical environment, so that immobile radionuclides become more mobile in the natural environment (e.g. more soluble in water, or more transportable by wind).

1.2 Regulatory context

Due to the presence of naturally occurring radionuclides originally associated with the gold bearing reefs of the Witwatersrand, the tailings material associated with the historical TSFs and ultimately those that will be deposited at on the RTSF are generally referred to as Naturally Occurring Radioactive Materials or NORM (IAEA, 2007).

NORM has the potential to impact negatively on the health of human beings if they are exposed to it. In South Africa, the protection of human health and the environment from adverse effects associated with exposure to ionizing radiation is regulated in terms of the National Nuclear Regulator Act (NNRA) (Act 47 of 1999) and the Nuclear Energy Act (NEA) (Act No. 46 of 1999). The NNRA established the National Nuclear Regulator (NNR) as the statutory body responsible for regulating the nuclear industry, as well as regulating NORM associated with the mining and mineral processing industry. The legal limit in terms of national standards (published in terms of the NNRA) for NORM to be classified as *radioactive* is 0.5 $Bq.g^{-1}$ or 500 $Bq.kg^{-1}$ (radionuclide specific). Section 22 (1) of the NNRA further states:

"*Any person wishing to engage in any action which is capable of causing nuclear damage (Section 2(1)(c)) may apply in the prescribed format to the chief executive officer for a Certificate of Registration (CoR) and must furnish such information as the board requires*".

Table 1-1 lists the four CoRs issued by the NNR in the past to SGL (or its predecessors) for operations affected by the WRTRP.

Table 1-1: The four Certificate of Registration issued to SGL by the NNR for those operations affected by the WRTRP.

No.	Operations	Certificate of Registration Issues by the NNR
1	Driefontein Operations	CoR-69
2	Kloof Operations	CoR-70
3	Ezulwini Operations	CoR-58
4	Cooke Operations	CoR-226

Key submissions to the NNR as part of the initial CoR application includes radiological worker and public safety assessments. The purposes of these assessments as part of the overall Radiation Management Programme (RMP) are, amongst others, to demonstrate to the NNR and other stakeholders that the potential radiological impact induced by the operation are within the compliance criteria set for the protection of human health against exposure to ionizing radiation. For this purpose, all potential sources of radiation exposure as defined in the Scope of the CoR have to be considered. In accordance with the regulatory process administered by the NNR, SGL has to obtain nuclear authorisation for the WRTRP. For existing operations, the NNR requires for this purpose the submission of Authorisation Change Requests (ACRs). The ACRs should affirm the proposed changes to the Scope of CoRs and, amongst others, demonstrate what the potential radiological impact of these changes would be to workers and members of the public. These are again in the form of radiological worker and public safety assessments.

1.3 Terms of reference

The purpose of this report is to present the radiological impact assessment prepared as part of the Environmental Impact Assessment (EIA) report (see Section 3) for the WRTRP. The Terms of Reference (ToR) for this report are consequently defined as to:

- Identify, describe and determine the likely significance of the potential radiological impact that may arise from to the different components of the WRTRP; and
- Recommend practical and cost-effective mitigation measures to minimise or avoid negative impacts, as well as enhancement measures to optimise the potential positive impacts of the operation.

2 Details of the Specialist

This report was compiled by Dr JJ van Blerk, a Radiation Protection Specialist (RPS) registered with the Accreditation Board of the South African Radiation Protection Association

(SARPA). Dr van Blerk has 25 years of experience in the field of radiation protection and radioactive waste management, in particular the radiological public safety assessment of mining and mineral processing facilities, and radioactive waste disposal facilities. A declaration of independence is included, while a more comprehensive CV are attached as Appendix A.

3 Aims and Objectives of the Report

The NNR administrates the nuclear regulatory process for projects involving NORM such as the WRTRP. Concurrently, national legislation requires an integrated environmental authorisation process for the approval of the WRTRP. SGL appointed Digby Wells Environmental (Digby Wells) as Independent Environmental Assessment Practitioner to undertake the environmental authorisation process for the WRTRP. This requires, amongst others, the development of various documents, including Scoping Reports, an EIA report, and an associated Environmental Management Programme (EMP).

The aim of this report is to present the radiological impact assessment of the WRTRP at a level that is sufficient for input into the broader environmental authorisation process. Radiological public safety assessments (RPSAs) prepared as part of the ACR submissions to the NNR is used as basis of this purpose, which is normally being done and presented at a greater level of detail. However, the impact assessment report is scoped and structured as a standalone report, suitable for inclusion in the EIA/EMP process as appropriate (see Section 4). To ensure that the radiological impact assessment is conducted in a robust, but systematic and transparent manner, the following serves as specific objectives for the report:

- To define in broad terms, the nuclear regulatory framework for the radiological impact assessment process in accordance international recommendations and guidance, as well as national legislation and supporting regulations.
- To provide a description of the WRTRP, as well as the environmental and radiological baseline conditions in sufficient detail to facilitate a Source-Pathway-Receptor analysis as basis to define and justify a discrete set of public exposure conditions as part of the radiological impact assessment process.
- To assess and analyse the radiological consequences of each public exposure condition for the different components of the WRTRP.
- To Identify, describe and determine the likely significance of the potential radiological impact that may arise from to the different components of the WRTRP, using predefined impact assessment criteria; and
- To recommend practical and cost-effective mitigation measures, including public radiation protection and monitoring measures that may be required to reduce the radiological impact to be in compliance with the regulatory framework, for inclusion in the EMP.

4 Scope and Structure of the Report

The report assumes a basic understanding of ionizing radiation and the effects of exposure to radiation on human health and the environment. If more information is needed on these subjects, the interested reader is referred to readily available literature resources, an example of which is a document entitled '*Radiation, People and the Environment*' published by the International Atomic Energy Agency (IAEA, 2004a).

SGL operates under four CoRs for operations affected by the WRTRP (see Table 1-1). The scope of this report is limited to the potential radiological impact induced by those operation specific components that will be affected by the WRTRP, and does not include the total operation as defined in the Scope of the CoRs.

The scope of this report is further limited to the potential radiological impact induced by the WRTRP to members of the public. The occupational exposure to workers as presented in a radiological worker safety assessment (RWSA) falls outside the scope of the EIA/EMP process and is thus excluded from the scope of this report. The remainder of the report is structured as follows (see also Figure 5-1):

- Section 5 provides an overview of the methodology that was followed to assess the radiological impact that may potentially be induced by the WRTRP.
- Section 6 defines the assessment context, as the regulatory and technical boundary conditions within which the assessment was performed.
- Section 7 provides a high level description of the WRTRP and its associated components that are relevant to the radiological impact assessment process.
- Section 8 provides a summary overview of the potentially affected environmental baseline conditions.
- Section 9 summarises the radiological baseline conditions as observed in the vicinity of the WRTRP, as well as the project related radiological conditions.
- Section 10 is devoted to a Source-Pathway-Receptor analysis, with the purpose to derive a discrete set of public radiation exposure conditions for the WRTRP.
- Section 11 provides a brief overview of the mathematical models that is required to evaluate the radiological consequences of the discrete set of public exposure condition. The models itself is presented as Appendix B to this report.
- Section 12 presents the consequence analysis, in terms of the potential total effective dose to members of the public induced by the different components of the WRTRP.
- Section 13 provides a qualitative discussion of sensitive and no-go areas from a radiological impact perspective as identified in the assessment.
- Section 14 uses the radiological dose assessment as basis to derive the impact assessment.

- Section 15 addresses the cumulative impact, both between facilities within the same CoRs, but also between different CoRs.
- Section 16 addresses unplanned and low risk events, which is often associated with accidents and incidents outside the normal operating conditions
- Section 17 presents actions to be included in the EMP that is, in terms of the regulatory framework administrated by the NNR, defined in the public Radiation Protection Programme (RPP).
- Section 18 highlights consultations that were undertaken in executing the assessment.
- Section 19 addresses issues identified as part of the comment and responses from stakeholders.
- Section 20 provides some high level conclusions and recommendations.

5 Methodology

5.1 Assessment framework

Various methodologies or assessment frameworks have been developed over the years that can be used to quantify the potential radiological impact of a mining and mineral processing operation to members of the public. None of these methodologies can be considered the only or correct approach. What is more important is that the methodological approach followed for an assessment of this nature is fit for purpose and induces confidence in the assessment results, with due consideration of the graded approach to safety assessments (IAEA, 2009).

Figure 5-1 illustrates the methodological assessment framework broadly followed in the RPSA process. It resembles the IAEA methodology developed for the safety assessment of near surface radioactive waste disposal facilities (IAEA, 2004b). Conceptual variations were introduced to make the framework more suitable for mining and mineral processing operations. The inherent nature of the revised framework is still systematic and structured, and provides for the continual improvement of the total system through an iterative process. Some of the key elements are (see Figure 5-1):

- Definition of the assessment context, with specific emphasis on the regulatory framework and the technical basis of the assessment (e.g. purpose and scope of the assessment, spatial and temporal boundary conditions, and assessment endpoints);
- Description of the total integrated system, including the operational processes and associated surface infrastructure, environmental baseline conditions, demographical and human behaviour conditions, as well as the radiological baseline conditions;
- Development and justification of public exposure conditions, using a Source-Pathway-Receptor analysis approach;

- Development of a System Level Model using Ecolego® as a software basis (http://ecolego.facilia.se/ecolego/show/HomePage). This includes the development of appropriate conceptual models for each exposure condition, as well as the necessary mathematical models implemented in Ecolego® to assess the radiological consequences of each exposure condition;
- Consequence analysis in terms of the dose criterion, including sensitivity and uncertainty analysis as appropriate; and
- Interpretation of assessment results in terms of the assessment context, including assessing the significance of the radiological impact of the WRTRP, with the dose criterion as basis.

A significant feature of the assessment framework is the interaction of *Process Level Modelling* with other elements of the framework. For the purpose of the impact assessment, *Process Level Modelling*, notably for the atmospheric-, groundwater and to a lesser extent the surface water pathways, were performed as part of specialist studies for the EIA process. The outcome of these studies were used and referenced in the system description, the development of public exposure conditions, and in the development of the *System Level Models* as appropriate and justified (see Section 5.2).

5.2 Literature review and desktop assessment

Due to the nature of mining and mineral processing operations and the radiological impact assessment process, integration of information from various disciplines are essential. For this reason, the assessment has drawn extensively on specialist studies and other project related reports as basis for the impact assessment. Section 21 provides a list of references used in the report. As a minimum, the following project reports were used extensively to ensure consistency and continuity:

- The high level project description prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015a)
- Scoping report for listed activities associated with the Driefontein Mining Right area, prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015b).
- Scoping report for listed activities associated with the Kloof Mining Right area, prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015c).
- Scoping report for listed activities associated with the Cooke Mining Right area, prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015d).
- Scoping report for listed activities associated with the Ezulwini Mining Right area, prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015e).

- The socio-economic scoping and impact assessment report prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015f).
- The groundwater impact assessment report prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015g).
- The air quality impact assessment report prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015h).
- The hydrology impact assessment report prepared as part of the environmental impact assessment process for the SGL WRTRP (Digby Wells Environmental, 2015i).

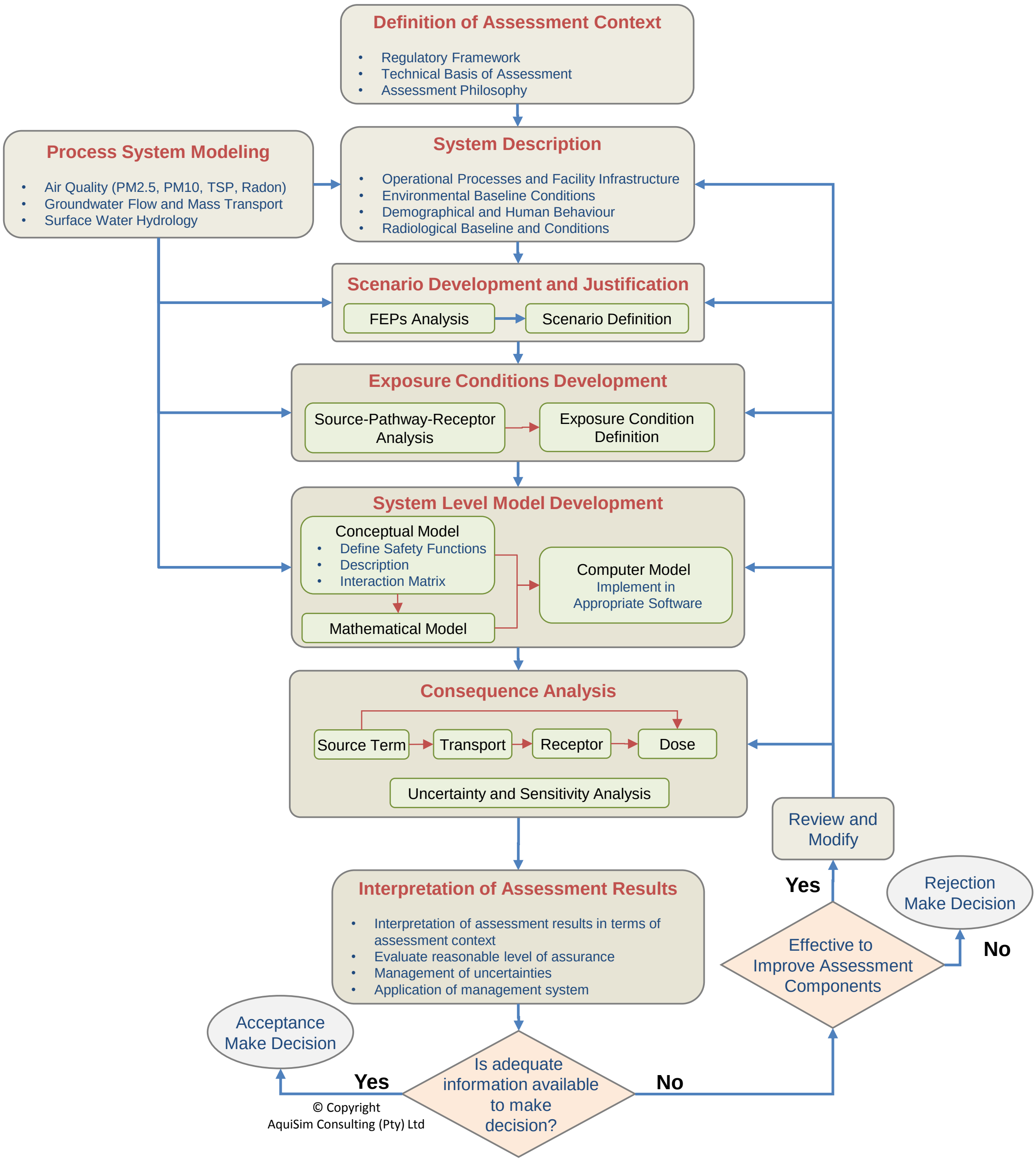

Figure 5-1: Schematic illustration of the safety assessment framework followed to quantify the radiological impact to members of the public induced by the WRTRP.

5.3 Fieldwork and seasonal influence

No specific fieldwork was performed as part of the preparation of the radiological impact assessment associated with the WRTRP. Rather, fieldwork required for this purpose was performed indirectly as part of the specialist studies referenced in this report, notably the social impact assessment study, the air quality impact assessment study, as well as the surface water and groundwater impact assessment studies.

Consistent with the regulatory process administrated by the NNR, a radiological baseline site characterisation study is required to establish conditions before operations commence. The preliminary outcome of this study, performed jointly by SGL and the South African Nuclear Energy Corporation (Necsa) as a subcontract to SGL, is documented in NECSA (2015). It presents the ambient gamma radiation at unaffected areas, the ambient airborne radon concentration, as well as the radiological conditions (based on full spectrum radioanalysis) in soils, sediments, vegetation, surface water and groundwater. Seasonal variations are covered to the extent possible and justified. It can be assumed that in most cases these observed conditions represents natural background radiation. Section 9.1 summarises the outcome of the baseline site characterisation study results available to date.

Note that the regulatory compliance criteria (see Section 6.4) represent the contribution from the SGL operations *above* natural background radiation. The observed baseline conditions therefore do not have an influence on the radiological impact assessment process or outcome.

6 Assessment Context

Generally, the *assessment context* defines the overall framework within which the assessment is conducted. It provides the means by which stakeholders are informed of what is included or excluded from the assessment and justification for the choices made. Viewed from this perspective, the assessment context defines the assumptions and constraints that reflect the regulatory framework, the technical basis (i.e., purpose, scope, and focus of the assessment), as well as the temporal and spatial boundary conditions of the assessment.

6.1 Regulatory framework

The regulatory framework is defined by a combination of national regulatory requirements and guidance, supplemented with principles, requirements, and guidance from international organisations concerned with radiation protection and the management of radioactive waste. The international radiation protection framework for the nuclear, medical, and mining industries is well established and recognised. Organisations that play a key role in this regard include the *United Nations Scientific Committee on the Effects of Atomic Radiation* (UNSCEAR), the *International Commission on Radiological Protection* (ICRP), and the *International Atomic Energy Agency* (IAEA).

The NNRA was introduced as the leading legislation for the protection of human health and the environment from adverse effects of ionizing radiation exposure (see Section 1.2). The NNR was introduced as the statutory body responsible for, among other, regulating mining and mineral processing facilities that carry out activities and operations involving NORM.

In terms of its mandate, the NNR must publish requirements, guidelines, and standards for the protection of persons, property, and the environment against radiation exposure. Two such documents that are applicable to the radiological impact assessment of from mining and mineral processing operations, are *Regulation on Safety Standards and Regulatory Practices* (Regulation 388 of April 2006) and *Regulatory Guide for Safety Assessment of*

Radiation Hazards to Members of the Public from NORM Activities (RG-002) (NNR, 2013a). The national dose limit and dose constraint defined in Regulation No. 388 for the protection of members of the public (see Section 6.4.1) are consistent with ICRP and IAEA guidance for public protection against exposure to ionizing radiation.

6.2 Stakeholders (target audience)

Stakeholders as used here are groups or individuals with an interest in a new or existing mining and mineral processing operation or those potentially affected by the radiological impact induced by the operations. The radiological impact assessment is then also undertaken to provide confidence to stakeholders that an operation does not pose a radiological risk to members of the public residing near the operation, *above the regulatory compliance criteria set for the radiation protection of members of the public.*

Stakeholders for this assessment include management and staff, regulatory authorities, members of the public and environmental interest groups. Local, provincial and national government departments and regulatory authorities (e.g. the NNR) serve as the main target audience, while other stakeholders that may have an interest in the assessment include:

- SGL management and staff, in particular those at the Driefontein, Kloof, Ezulwini and Cooke Operations involved in, or responsible for, the implementation of the WRTRP;
- Local, provincial, district, and national government departments and regulatory authorities, in particular the NNR;
- The public residing near the SGL operations that will directly or indirectly be affected by the WRTRP, including communities, agriculture (farmer's associations), landowners, and land occupiers;
- Business and industry, including ward councillors, labour unions, small to medium enterprises, mines, industrial and large business organisations; and
- Technical, scientific, semi-Government entities (parastatals), and Non-Governmental Organisations (NGOs) (e.g., environmental organisations, community-based organisations) that might have an interest in the approach being followed and the outcome of the assessment results.

6.3 Technical basis of the assessment

Safety assessments can be performed for different purposes as part of the overall management of mining and mineral processing operations. As the operation moves from the pre-operational to operational and post-operational phases, the scope and focus of the assessments may vary.

Before operations commence, a pre-operational safety assessment is performed on a *prospective* basis to assess whether the proposed operations do not pose a radiological risk to members of the public above the regulatory compliance criteria. Once operational, the prospective assessment is updated with a site-specific facility or operation safety assessment, as appropriate.

6.3.1 Aim and objectives of the assessment

The aim and objectives of the assessment are similar to the aim and objectives of the report presented in Section 3. The aim of the assessment is to evaluate the potential radiological safety and impact to members of the public in a comprehensive, systematic, and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements and regulations in general. The following serves as specific objectives of the assessment:

- To use the outcome of the radiological public safety assessment as basis to identify, describe and determine the likely significance of the potential radiological impact that may arise from to the different components of the WRTRP, using predefined impact assessment criteria for input into the EIA/EMP process.
- To recommend practical and cost-effective mitigation measures, including public radiation protection and monitoring measures that may be required to reduce the radiological impact to members of the public to be in compliance with the regulatory framework, for inclusion in the EMP.

6.3.2 Scope and focus of the assessment

Consistent with the aim and objectives of the assessment, the focus of this assessment is the potential radiological impact to members of the public induced by the WRTRP, for input into the EIA/EMP process. The potential radiological impact to workers (i.e., the occupational radiation exposure) falls outside the scope of the assessment.

The WRTRP has not yet commenced, which means that the assessment presented in this report is *prospective* in nature, based on currently available information.

The WRTRP influences four operations with four separate CoRs. The scope of the assessment presented here is limited to specific components of the WRTRP and does not include the potential radiological contribution of the total operation of each CoR. However, the cumulative contribution of project components within each CoRs and between CoRs is considered where applicable and justified.

6.4 Assessment endpoint

6.4.1 Radiological assessment endpoints

Consistent with the ICRP System of Protection, the primary assessment endpoint is the annual individual effective dose rate (unless otherwise stated, the term *dose* refers to the annual individual effective radiation dose, calculated using the method described in ICRP (1991)). This is consistent with the NNR requirements for the radiological protection of members of the public and adopted in the Regulation on Safety Standards and Regulatory Practices (Regulation 388).

Consistent with Regulation 388, RG-002 states the following with regard to radiation protection criteria for members of the public:

> *For members of the public, the dose constraint applicable to the average member of the critical group within the exposed population is 250 µSv per annum specific to the authorised action unless otherwise agreed by the Regulator on a case-by-case basis, taking into account the dose limit of 1 mSv to exposure of members of the public from all sources. (This value excludes natural background).*

The radiological impact assessment for the WRTRP considers the 'Target Dose' of 250 µSv per annum as compliance. However, the public dose limit is 1 mSv (1 000 µSv) per annum. A total effective dose of between 250 µSv and 1 000 µSv per annum for an authorised action would therefore not constitute non-compliance with respect to public exposure.

6.4.2 Complementary assessment endpoints

Activity concentrations in environmental media may serve as complementary assessment endpoints. While it may not be necessary from a compliance perspective, reporting these endpoints contributes to the overall transparency of the assessment. Therefore, radionuclide concentrations in various environmental media can be used as additional safety indicators to complement the dose criterion. These can be compared with natural background concentrations in environmental media as observed near the site. Activity concentrations in the following environmental media may be reported:

- Airborne dust activity concentration for PM_{10} (in units of $Bq.m^{-3}$);
- Dust deposition rate for Total Suspended Particulates (TSP) (in units of $Bq.m^{-2}.a^{-1}$);
- Airborne radon concentration (in units of $Bq.m^{-3}$);
- Radon exhalation rate from area sources (in units of $Bq.m^{-2}.s^{-1}$);
- Activity concentration in surface water or groundwater (in units of $Bq.m^{-3}$ or $Bq.L^{-1}$); and
- Activity concentration in surface soils or sediments (in units of $Bq.kg^{-1}$).

6.4.3 EIA endpoints

The radiological impact is assessed based on the impact's magnitude as well as the receiver's sensitivity, culminating in an impact significance which identifies the most important impacts that require management. Based on international guidelines and South African legislation, the following criteria are taken into account when examining potentially significant impacts (see Section 14.1):

- Nature of impacts (direct/indirect, positive/ negative);
- Duration (short/medium/long-term, permanent(irreversible) / temporary (reversible), frequent/seldom);
- Extent (geographical area, size of affected population/habitat/species);

- Intensity (minimal, severe, replaceable/irreplaceable);
- Probability (high/medium/low probability); and
- Possibility to mitigate, avoid or offset significant adverse impacts.

6.5 Spatial and Temporal Boundary Conditions

6.5.1 Spatial domain of concern

The spatial domain is largely dictated by an understanding of the processes governing the movement of radionuclides and exposure pathways for the potentially exposed groups. While physical boundaries cannot be applied rigorously to some of these processes, a radius of 3 to 5 km around the physical extent of the WRTRP infrastructure defines the area, in which environmental pathways is considered in the assessment.

A wider study area may be defined and justified to accommodate processes governing the movement of radionuclides beyond these boundaries. However, the spatial scale is likely to be limited by the selected exposure conditions. Since the intent of the analysis is to evaluate critical groups, the exposure locations to be evaluated are likely to be near the sources.

As part of communication to stakeholders, there may be an interest in evaluating impacts at greater distances than would be considered from a purely regulatory standpoint. That is, the critical group for comparison with regulatory criteria may be nearby the facility, but more distant locations may be of interest to members of the public living further away, even though they are at lower risk than the critical group. The decision to include these broader conditions and associated larger spatial scales, is taken as needed as part of the development of exposure conditions.

6.5.2 Assessment timescales

The scope of the assessment recognises the need to consider the full life cycle of a mining and mineral processing operation, in particular the operational and post-operational phases. Consideration of the post-operational phase is included because some of the radiation sources will remain following closure. Properties (e.g. half-life) of U-238, U-235 and Th-232 and their associated decay products suggest that some of the remaining radiation sources may be hazardous indefinitely.

Furthermore, for decay chains that are not currently in secular equilibrium, there is the potential for the hazard of the waste to increase as time increases. This effect is of particular concern for the U-238 decay chain, when U-238 is in disequilibrium with Ra-226. As time increases, Ra-226, and its radiotoxic progeny (i.e., Rn-222, Pb-210, and Po-210) can be expected to increase, and this increase continues over time scales exceeding one million years. The implication is that there is no natural time scale, at which the safety assessment analysis can be truncated using the argument that the peak hazard has been evaluated. One has to recognise also that over these almost indefinite timescales, natural processes such as wind and water erosion has the potential to spread and disperse surface area sources into the wider environment.

Note that current national regulations do not prescribed an assessment period that has to be considered in the dose assessment process, other than to focus on the operational phase and to determine peak doses for long-term processes (NNR, 2013a).

7 Description of the West Rand Tailings Retreatment Project

The purpose of this section is to provide a summary description of the WRTRP and associated surface infrastructure. Within the conceptual assessment framework presented in Figure 5-1, this information serves as input into the source characterisation (and associated source term analysis).

7.1 Background

SGL (formerly known as GFI Mining South Africa (Pty) Limited) used to be a subsidiary within the Gold Fields Group. In early 2013, Gold Fields unbundled its Kloof Driefontein Complex (KDC) and Beatrix gold mines in the Free State to create SGL and listed it as a fully independent company on both the JSE and the NYSE Stock Exchanges. In parallel, in 2012, Gold One International Limited (Gold One) acquired Rand Uranium Limited (Rand Uranium) and in the same year acquired the Ezulwini Mining Company (Pty) Ltd (Ezulwini) in an agreement with First Uranium Corporation. Subsequently, in October 2013, SGL acquired the interest held by Gold One in Rand Uranium and Ezulwini. The Gold One assets that are now part of SGL comprise the Cooke Operations (underground mining and surface reclamation operations) that currently produce gold and uranium.

7.2 Project history

The treatment of historical TSFs in the West Rand area has a long history with Gold Fields, Rand Uranium, Harmony Gold Mining Company Ltd (Harmony), Gold One and SGL, with a number of parallel, independent studies relating to the treatment of these facilities completed.

Prior to the creation of SGL in 2013, Gold Fields had embarked on the West Wits Project (WWP), aimed at retreating several historical TSFs on the West Rand to recover residual gold, uranium and sulphur (where viable), and storing the tailings on a new Central TSF (CTSF). Similarly, Rand Uranium had embarked on the Cooke Uranium Project (CUP) and the associated Cooke Optimisation Project (COP), which endeavoured to treat the Cooke TSF for gold, uranium and sulphur and ultimately deposit the tailings on to the proposed Geluksdal TSF. Essentially two independent projects with similar processing infrastructure and deposition sites, within a 25 km radius of each other.

In late 2009, Gold Fields and Rand Uranium met to evaluate the potential synergy of an integrated flow sheet for the CUP and the WWP, both of which were nearing feasibility completion. However, a significant amount of re-engineering and confirmatory test work would have been required to achieve this and, given the momentum of the respective projects, it was agreed that the investment would not be justified at that point in time. After the completion of the respective projects, they were put on hold because of economic circumstances at the time.

The WRTRP integrates the WWP and CUP into one project. All the surface TSFs and current arisings tailings, previously under the control of Gold Fields, Rand Uranium and Ezulwini, are to be centrally processed through the CPP and the residue deposited onto the RTSF.

7.3 Project location

Viewed simplistically, the historical TSF holdings of SGL in the West Rand that are of concern to the WRTRP can be divided into four Mining Right areas, namely the Kloof, Driefontein, Cooke and the Ezulwini. Figure 7-1 and Figure 7-2 show that these Mining Right areas are primarily located within the West Rand District Municipality (WRDM) of the Gauteng Province of South Africa. The WRDM consists of four local municipalities (LM), namely: Mogale City, Westonaria, Randfontein and Merafong City. The project area is primarily located within the Merafong City and Westonaria LM. Note that Merafong City LM is situated in the North-West Province, but is administrated as part of Gauteng.

Towns and larger settlements located within the broader project area include Randfontein, Mohlakeng, Carletonville, Westonaria, Venterspost, Rietvallei, Bekkersdal, Toekomsrus, Modderfontein, and Fochville (see Figure 7-1 and Figure 7-2).

The project area also includes a large number of historical and existing mining activities. However, the proposed CPP and RTSF comprise ‘greenfield’ projects. Pipeline routes will, as far as possible, follow existing road- and power line servitudes.

7.4 Ultimate project

Figure 7-3 shows the layout of primary infrastructure associated with the ultimate WRTRP between the four Mining Right areas. Each of these Mining Right areas contains the following historical TSFs (see Figure 7-4 to Figure 7-7):

- Driefontein Mining Right area: Driefontein 1, 2, 3, 4 and 5 TSFs. Once the Driefontein 3 and 5 TSFs have been depleted, the remainder of the Driefontein TSFs, namely Driefontein 1, 2 and 4 TSFs, will be processed through the CPP;
- Cooke Mining Right area: Cooke TSF and the Millsite Complex (38, 39 and 40/41 and Valley) TSFs. The Cooke TSF will be processed subsequent to Driefontein 3 and 5 TSFs and in parallel with the Cooke 4 South TSF. Millsite Complex will be processed with the concurrent construction of Module 2 float and gold plants;
- Ezulwini Mining Right area: Cooke 4 South TSF, which will be processed subsequent to Driefontein 3 and 5 TSFs and in parallel with the Cooke TSF; and

- Kloof Mining Right area: Kloof 1 TSF, Kloof 2 TSF, Leeudoorn TSF, Libanon TSF, Venterspost North and Venterspost South TSFs. Venterspost North and South TSFs will be processed with the concurrent construction of Module 2 float and gold plants. The remainder of the TSFs will be processed once Module 3 of the CPP has been constructed.

Each Mining Right area will be reclaimed in a phased approach. As part of the Initial Implementation (see Section 7.5 and Figure 7-8), the Driefontein 3 TSF, concurrently with the Cooke TSF will be reclaimed first. Following reclamation of Driefontein 3 TSF, Driefontein 5 TSF and Cooke 4 South TSF will be reclaimed.

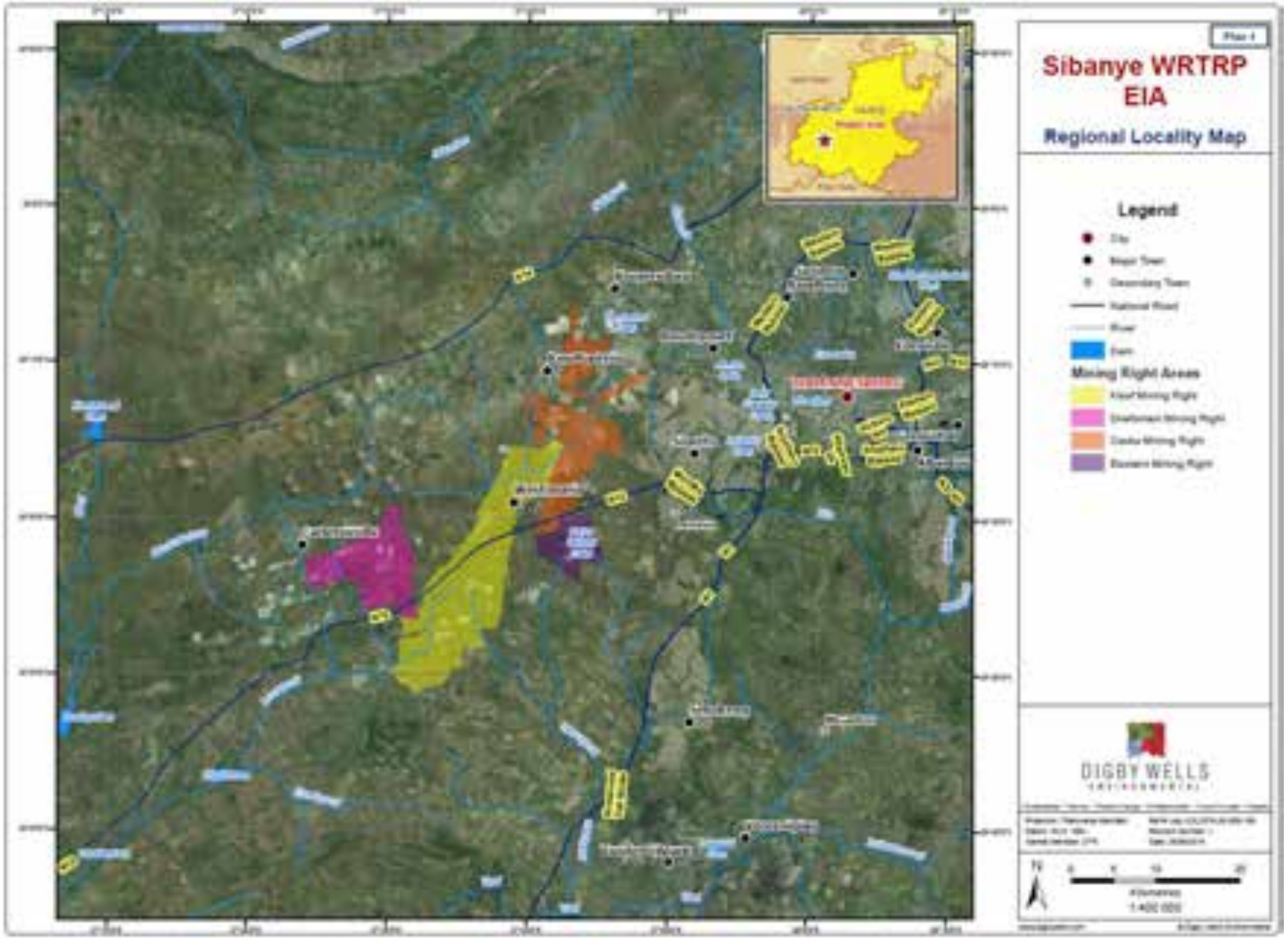

Figure 7-1: Regional locality map, showing the four Mining Right areas of concern to the WRTRP.

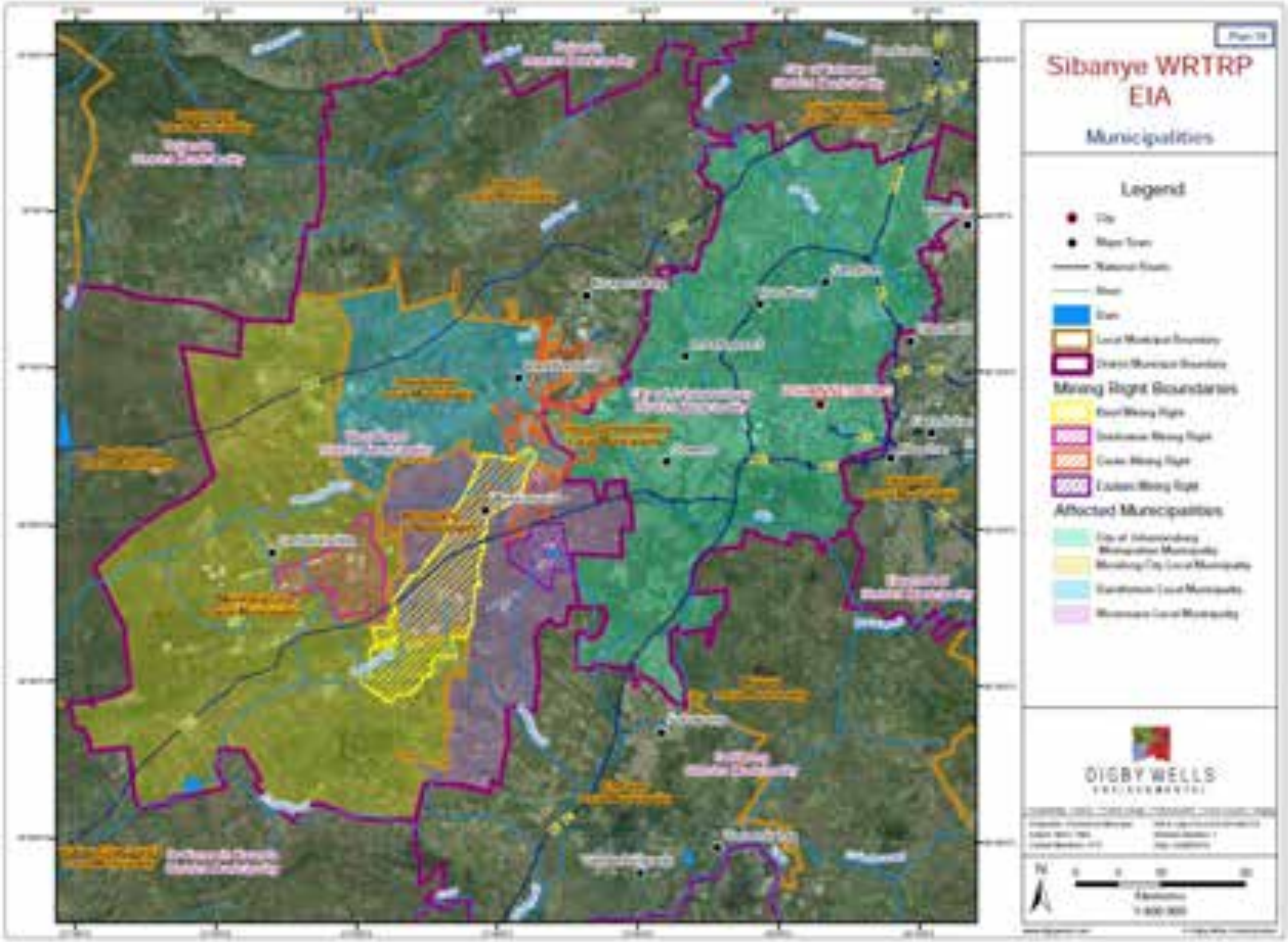

Figure 7-2: Locality map showing that the Kloof, Driefontein, Cooke and Ezulwini Mining Right areas are primarily located within the West Rand District Municipality (WRDM) of the Gauteng Province of South Africa.

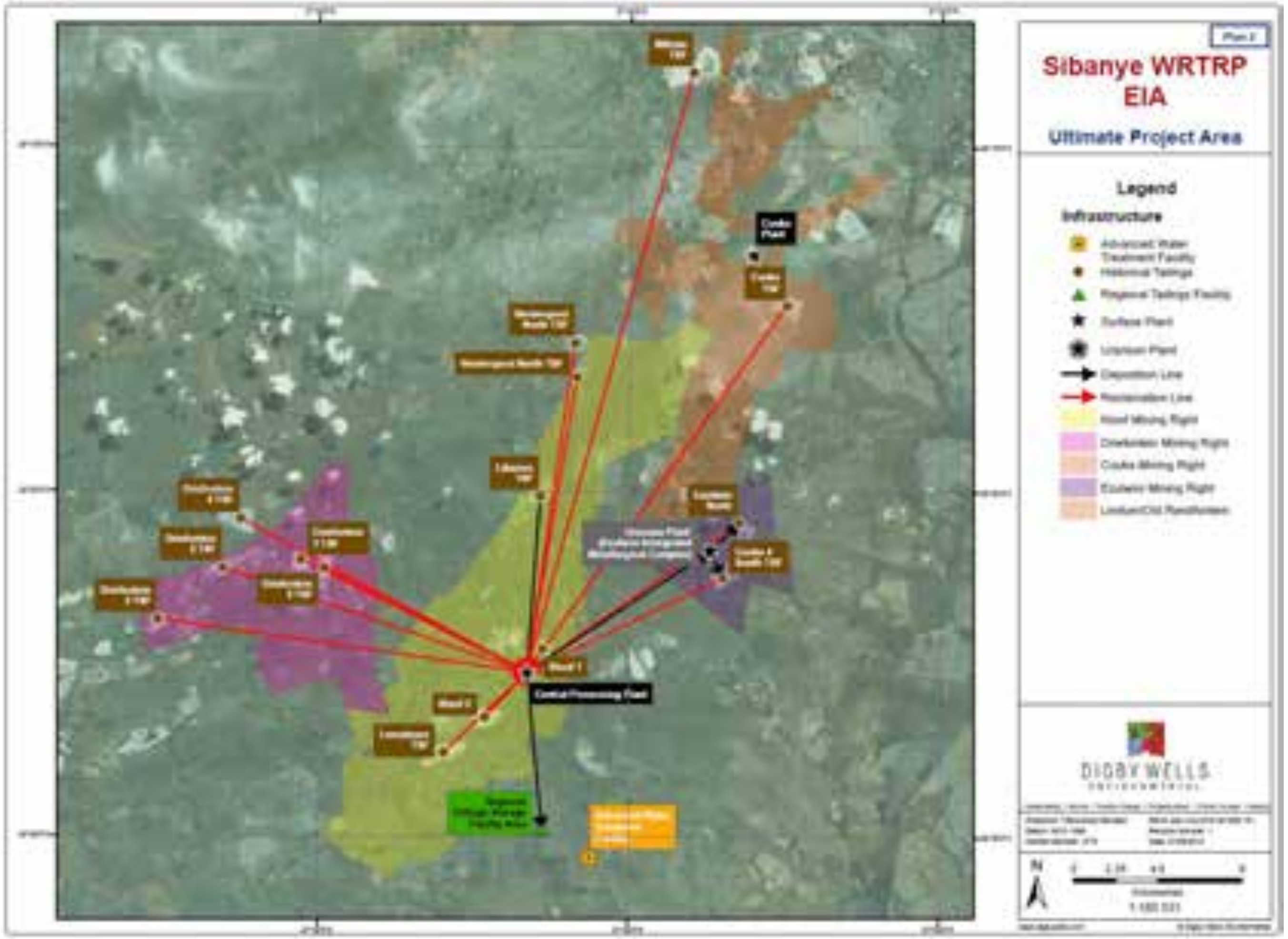

Figure 7-3: Locality map showing the layout of primary infrastructure associated with the ultimate WRTRP between the four Mining Right areas.

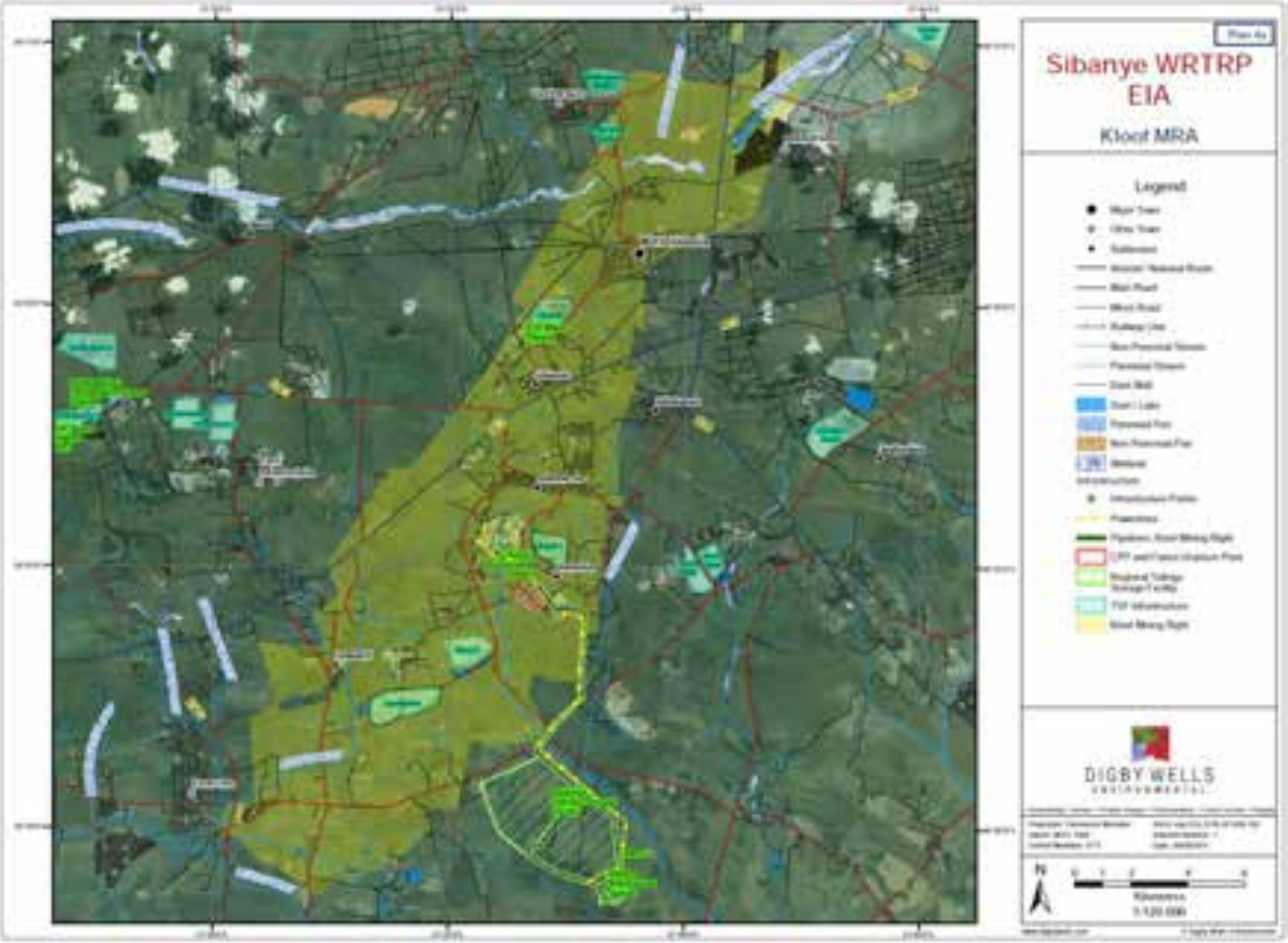

Figure 7-4: Locality map showing the Kloof Mining Right area.

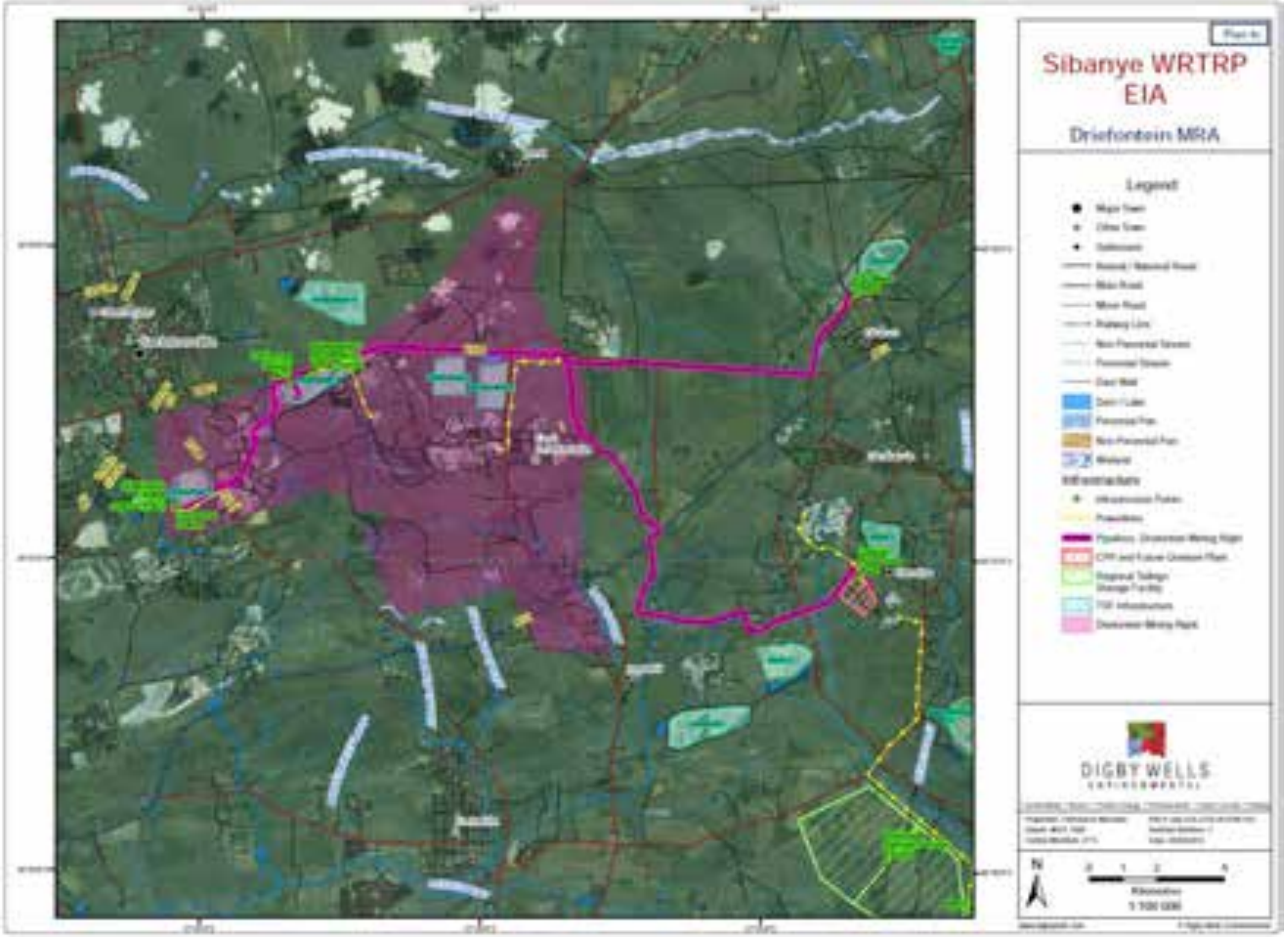

Figure 7-5: Locality map showing the Driefontein Mining Right area.

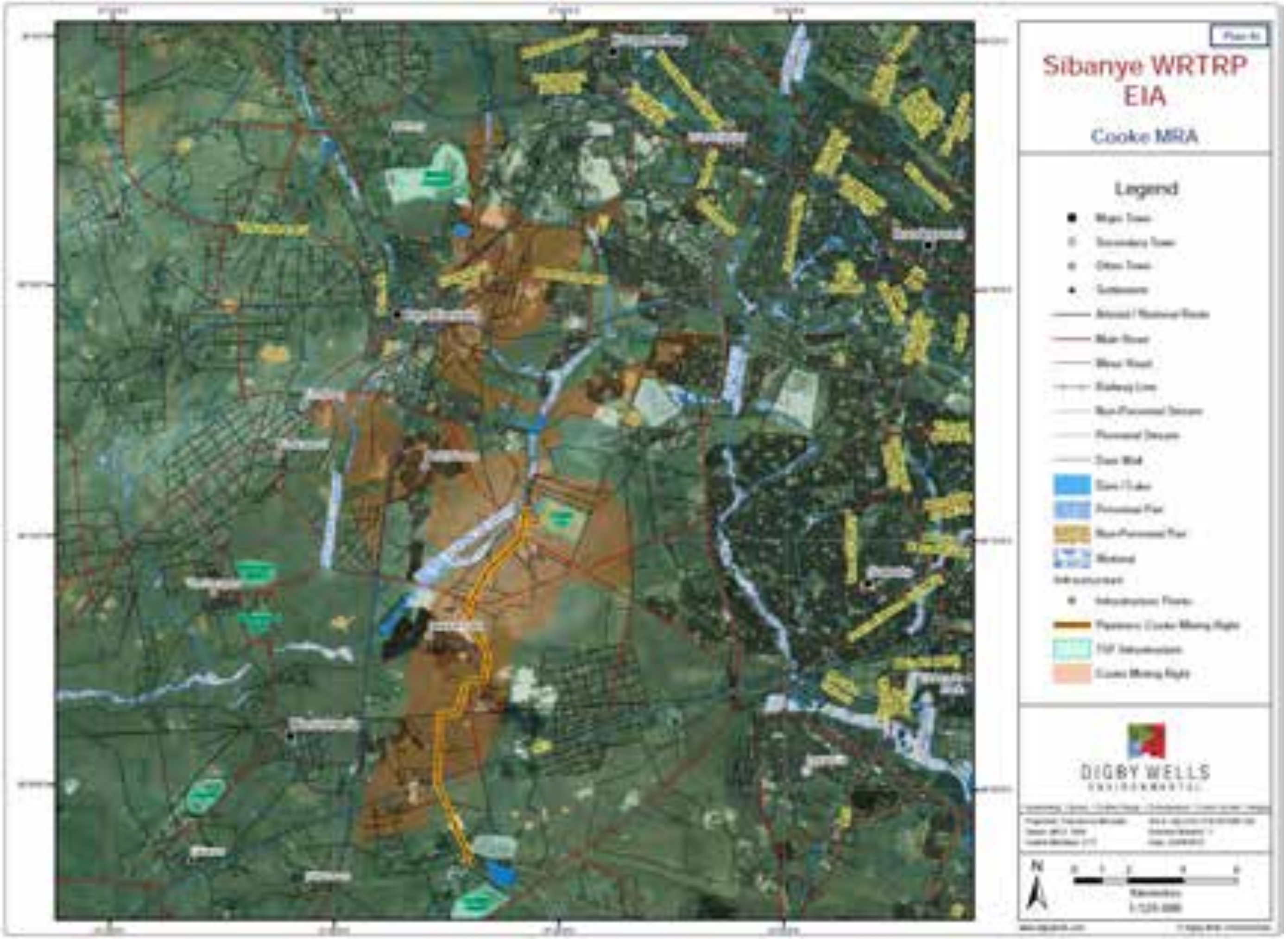

Figure 7-6: Locality map showing the Cooke Mining Right area.

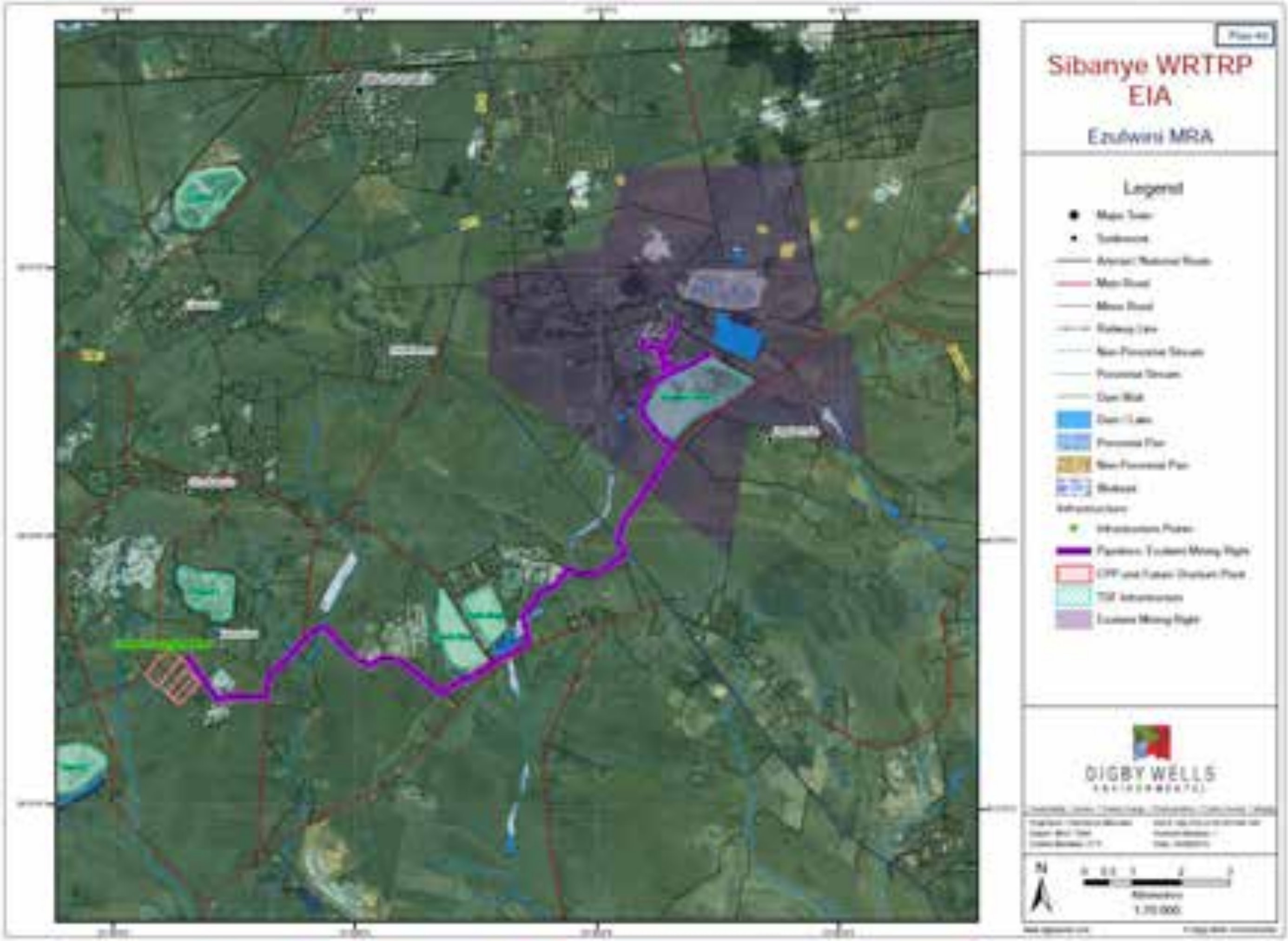

Figure 7-7: Locality map showing the Ezulwini Mining Right area.

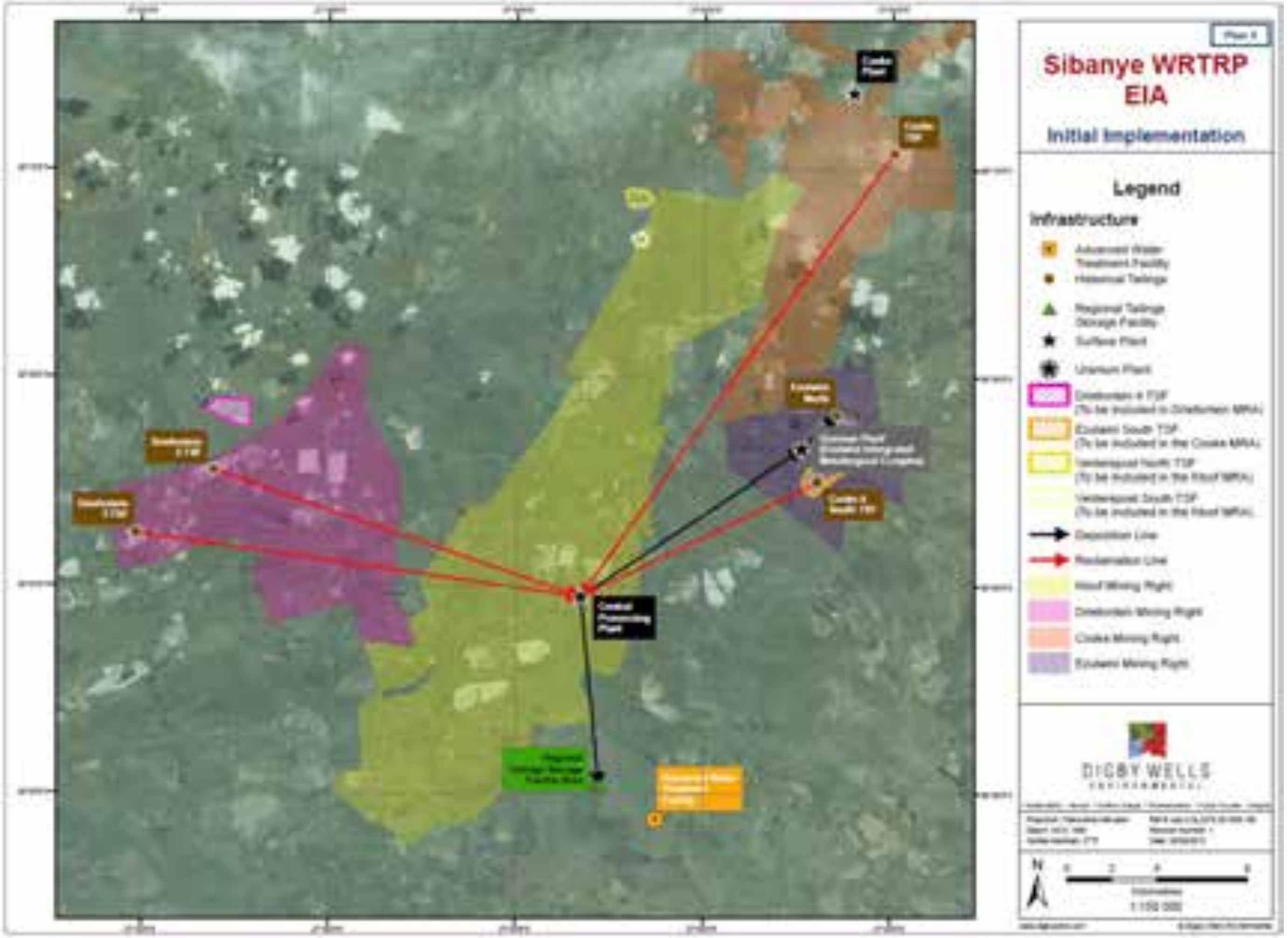

Figure 7-8: Locality map showing the layout of primary infrastructure associated with the initial implementation of the WRTRP.

Once commissioned, the WRTRP will initially reclaim and treat the TSFs at a rate of 1.5 Mt per month; 1 Mt per month from Driefontein 3 TSF, followed sequentially by Driefontein 5 TSF and Cooke 4 South TSF and 0.5 Mt per month from Cooke TSF. Reclamation and processing capacity will ultimately ramp up to 4 Mt per month over an anticipated period of 8 years. At 4 Mt per month tailings retreatment capacity, each of the TSFs in the Mining Right areas will be reclaimed and processed simultaneously, together with the underground arisings.

The reclaimed tailings material will be treated at the CPP. In addition to gold and uranium extraction, sulphur will be extracted to produce sulphuric acid, which will be reused in the leach section of the uranium plant. To ensure the economic viability of the project, the upfront capital required for the WRTRP will be minimised, which is the reason why only essential infrastructure will be developed during the Initial Implementation phase (see Section 7.5). Existing and available infrastructure may be used to process gold and uranium until the volumetric increase in tonnage necessitates the need to expand the CPP.

The authorisation, construction and operation of the RTSF for the deposition of residue from the CPP will be located in an area that has been extensively studied as part of the WWP and the CUP. The RTSF is anticipated to accommodate the entire tonnage from the WRTRP. If proved viable, the RTSF will be one large facility as opposed to the two independent deposition facilities proposed by the WWP and CUP.

SGL already has various authorisations and approvals for elements of the WWP and CUP, with authorisations and approvals for certain aspects of the respective projects still outstanding. The WRTRP aims to combine the WWP and CUP, as per stakeholder concerns and suggestions based on the WWP and CUP. Should the WRTRP not proceed, SGL will continue with the WWP and CUP for activities that have been authorised, and proceed with the application process for the outstanding authorisations.

7.4.1 Water Sources

SGL recognise that water is a scarce and strategic commodity and hence currently impacted mine water will be used preferentially over Rand Water or other higher quality sources. For this reason, a number of water sources have been identified, from which water can be abstracted for the reclamation process. These include K10 shaft within the Kloof Mining Right area, as well as Cooke 1, Cooke 2, and Cooke 4 shafts within the Cooke Mining Right area. Water from these sources will be diverted to the reclamation areas via pipelines and Bulk Water Storage Facilities (BWSF) in the different Mining Right areas.

Once the impacted mine water, supplemented by recovered water from the various thickeners, has been used in the hydraulic reclamation process, it will find its way to the RTSF as carrier water for the retreated tailings. As process and rain water builds up on the RTSF, it will be drained to the Return Water Dam (RWD), from where it will be treated through the AWTF to potable standards (SANS 241:2011), depending on the final use.

7.4.2 Reclamation of tailings

The tailings reclamation process is essentially a water hydraulic mining operation, where the TSFs will be hydraulically reclaimed to the natural ground level in nominal 12 to 15 m benches and the foot print rehabilitated to a suitable end land use.

Water will be supplied to the various reclamation sites from existing impacted mine water sources (see Section 7.4.1), and then pressurised through a high pressure pumping system before reporting to the monitoring guns at the top of the historical TSFs. Monitoring guns will be used at the reclamation site mining face to transform the tailings material into a slurry.

The reclaimed material will flow through open channels over screens to remove oversized debris from the slurry before it enters a collection tank. A series of pumps will then pump the slurry from the tanks via thickeners to the CPP for gold, uranium and sulphur extraction.

Table 7-1 shows that the historical TSFs proposed for reclamation cover a total area of approximately 1660 ha. The RTSF footprint area will be approximately 1350 ha, liberating a nett 310 ha of currently sterilised land.

Table 7-1: Total area covered by the historical TSFs that will be reclaimed as part of the WRTRP.

Block	Name	Area (ha)	Block	Name	Area (ha)
Northern Block	Venterspos N	60.68	Western Block	Driefontein TSF 1	87.15
	Venterspos S	30.51		Driefontein TSF 2	85.26
	Millsite Complex	315.47		Driefontein TSF 3	72.76
	Cooke TSF	178.99		Driefontein TSF 4	165.66
	Total	**585.65**		Driefontein TSF 5	67.72
Southern Block	Kloof TSF 2	72.76		Libanon TSF	93.64
	Kloof TSF 1	86.99		**Total**	**572.19**
	Leedoorn TSF	186.27			
	Ezulwini South	157.99	Potential future TSFs	South shaft and Twin shaft TSFs	107.66
	Total	**504.01**			

7.4.3 Pipelines

The overland slurry and water piping required for the WRTRP will ultimately consist of approximately 120 km of pipeline (many of which will be parallel and in the same servitude). Existing mine servitudes will be utilised as far as possible for the overland piping. The following pipelines will be required (see Figure 7-4 to Figure 7-7):

- Water supply pipelines (from K10 shaft to the west BWSF, from Cooke 1 and 2 shafts to the Cooke BWSF, from Cooke 4 shaft to the south BWSF and from the respective BWSFs to the historical TSFs);
- Slurry pipelines (from the historical TSFs to the West Block Thickener (WBT), North block Thickener (NBT) and Cooke Thickener);
- Thickened slurry pipeline (from the WBT, SBT and Cooke Thickener to the CPP.);
- Uranium and sulphide rich slurry pipeline (from the CPP to Ezulwini);
- Tailings pipeline (from the CPP to the RTSF); and
- Treated water pipeline (from the AWTF to a discharge point on the Leeuspruit).

Table 7-2 summarises the routes, lengths and type of pipeline that will be implemented.

Table 7-2: Summary of the routes, lengths and type of pipeline that will be implemented as part of the WRTRP.

Name	Length (m)	Type
DRI3 to WBT	7 665	Slurry Pipeline -dilute
DRI5 to DRI3	6 646	Slurry Pipeline -dilute
WBT to CPP	17 473	Slurry Pipeline -thickened
Cooke TSF to Cooke Thickener	TBC	Slurry Pipeline-dilute
Cooke Thickener to CPP	TBC	Slurry Pipeline-thickened-existing approved route GDARD,NNR
Ezulwini South TSF to CPP	TBC	Slurry Pipeline-thickened
CPP to RTSF	17 908	Tailings Pipeline – thickened (alternate routes)
CPP to Ezulwini	18 502	Tailings Pipeline (Uranium Rich) - dilute
BWSF to DRI3	7 699	Water Pipeline
BWSF to DRI5	14 168	Water Pipeline
K10 to west BWSF	10 477	Water Pipeline
Cooke shafts to Cooke TSF	TBC	Water Pipeline – existing approved route GDARD , NNR
Cooke 4 shaft to Cooke 4 South TSF	TBC	Water Pipeline
RWD to AWTF	1 960	Water Pipeline
WBT to CPP (Alternative Route)	13 284	Slurry Pipeline (Alternative Route)

7.4.4 Thickeners

Thickener will be constructed for the respective Mining Right areas. The 65 m diameter concrete thickeners will be used to thicken reclaimed tailings from the historical TSFs before it is pumped to the CPP for processing. The thickeners provide a slurry of consistent density, and are critical in the optimisation of the operating of the CPP. The thickeners also aid in minimising pumping costs by optimising the amount of water pumped around the circuit.

7.4.5 The Central Processing Plant

The anticipated location for the CPP is mid-way between Kloof Main and Kloof 4 shafts, central to all the resources, water and power supply as well as existing and planned infrastructure (see Figure 7-4). The CPP, which will be developed in phases to eventually treat up to 4 Mt per month of historical tailings and current arisings, will eventually comprised of the following:

- Three Gold Plant Modules with a stack for each gold module;
- Two uranium processing plants, with a stack for each uranium plant;
- Two roasters and associated infrastructure, with a stack for each roaster;
- Acid plants and associated infrastructure, including stack;
- One boiler, and associated infrastructure, including stack;
- Float plants and associated infrastructure (one associated with the uranium plants);
- Bulk sulfuric acid storage facility;
- Loading facilities for uranium concentrate, bulk sulfuric acid and reagents;
- Bulk Water Storage Facilities; and
- Pollution control dams.

The use of the boiler will be limited to starting up the uranium plant and during plant shut down. In addition, as the production of acid in the plant will be an exothermic reaction, the heat generated as a by-product will be used to power the plant, thus augmenting the power supply from the national grid (Digby Wells Environmental, 2015h).

7.4.6 Regional Tailings Storage Facility

The RTSF will be located on a site originally known as B2/B3 as part of the WWP (site 33/34 from the CUP (Geluksdal Project). This was the alternate site for the CTSF, shown in Figure 7-9. The RTSF is situated south west of the current Doornpoort TSF, which is operated by Gold Fields. It will be 1350 ha in size, with a final height of 100 m.

The RTSF has been positioned and sized as a facility that can cater for both the tailings generated by the WRTRP, as well as other tailings located in the region approximating 1.3 billion tonnes. It is likely that the construction of the RTSF will be phased (initial 1.5 Mt per month progressing to up to 4 Mt per month) to suit the envisaged tonnage build up. Auxiliary infrastructure to be constructed as part of the RTSF complex includes:

- A penstock tower;
- Penstock outlet pipeline;
- Silt traps;
- Cascade ponds; and

- RWD.

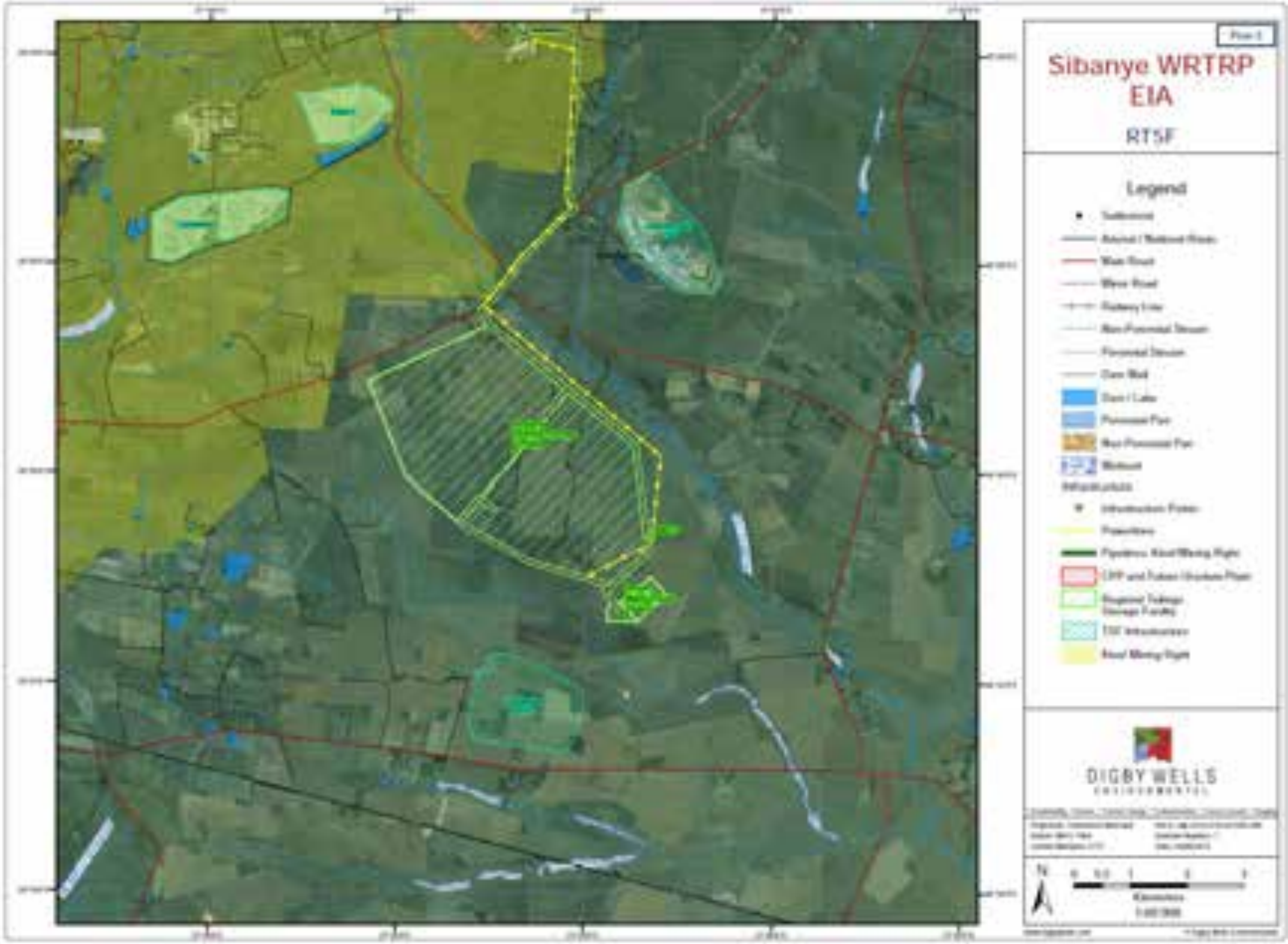

Figure 7-9: Locality map showing the RTSF in relation to Geluksdal site and other TSFs in the area.

7.4.7 Return Water Dam

The design and management of the RWD will need to be undertaken in line with the requirements of the GN 704 regulations. The RWD has therefore been sized to ensure that it is unlikely to spill into any clean water system more than once in 50 years, given a certain return water and/or water treatment rate.

The ultimate RWD arrangement, which will consist of a series of compartments due to the phased development of the RTSF, will require a total storage capacity of at least 3.5 million m^3. To limit seepage of process water, the RWD will be lined with a geocomposite liner consisting of a geomembrane underlain by a 300 mm thick layer of clayey material. A seepage collection system will also be provided to intercept and identify any leakage. Figure 7-9 shows the proposed location of the RWD relative to the RTSF.

7.4.8 Advanced Water Treatment Facility

The design by Watercare Mining (WCM) consists of a multiple stage softening and membrane separation process. The method of softening uses a Crystalactor® process for softening which reduces the incoming water hardness by the precipitation of calcium pellets. Through pH control and a feed crystal source of fine quartz sand, precipitation is controlled and creates fine pellets that are highly stable and easy to handle. This effectively combines the softening and clarifying stage in one process. This is followed by GAC (granular activated carbon) and Nano-filtration to remove all solids as well as organic compounds to protect the Reverse osmosis (RO) membranes from damage and fouling. The filtrate from the first stage membranes is below the prescribed quality and the brine is sent to a secondary Crystalactor® for softening again and follows the same processes as described by Stage 1. Three stages are used to create an overall water recovery of 93% with the solid waste discharged as stable pellets at an approximate water content of only 5%. Each stage of RO membrane recovery ranges from 65% to 50%, with each consecutive stage being lower recovery due to the saturation limit as well as the operating pressure being kept as low as possible to conserve energy.

The options for disposal of the pellets is either by creating a slurry that is pumped to the RTSF, or it needs to be collected on a drying bank and collected with a tipper and driven to the RTSF for disposal. The footprint of the proposed plant is approximate area of 3 600 m^2.

7.4.9 Summary

Table 7-3 provides a summary of the scheduled activities as part of Ultimate WRTRP.

Table 7-3: Scheduled Activities of the WRTRP – Ultimate Project

Proposed Construction Date*	**2016**	**2018**	**2020**
Operation Date	**2019**	**2021**	**2024**
Activities	▪ Treat Driefontein 3 and 5, Cooke 4 South TSFs (@1Mt per month) and Cooke TSFs at 0.5Mt oer month totalling 1.5 Mt per month through Gold Module 1, uranium roaster and acid plants of the new CPP with deposition onto the RTSF. ▪ High grade uranium concentrate (50 kt per month) transported and treated at Ezulwini uranium plant.	▪ Kloof 1 and 2 TSFs and current arisings ▪ Reclaim Leeudoorn and associated Mine TSFs ▪ Potentially South Deep Mine TSFs (future) and current arisings tail will go through CPP (high Uranium) ▪ Reclaim Millsite TSF	▪ Continue to reclaim Millsite TSF (39, 40, 41 and Valley) ▪ Reclaim Ventersport North and South Mine TSFs
Existing infrastructure to be leveraged	▪ Ezulwini Uranium Plant (50 kt per month) to treat concentrate from the CPP		

New infrastructure required	▪ CPP Gold Module I (footprint of full capacity to be authorised now):
	  ▪ Gold Plant I
	  ▪ Sulphide and oxide Floatation Plant
	  ▪ Uranium Plant 1
	  ▪ Acid Plant
	  ▪ Roaster 1
	▪ RTSF (footprint of full capacity to be authorised)
	▪ WBT and bulk water storage
	▪ Pipelines between Driefontein 3 and Driefontein 5, Cooke 4 South, Cooke TSF, WBT, CPP and RTSF
		▪ CPP Gold Module II:
		  ▪ Gold Plant II
		  ▪ Pipelines, roads and pumps
		  ▪ Thickener
			▪ CPP Gold Module III:
			  ▪ Gold Plant III
			  ▪ Uranium Plant II
			  ▪ Pipelines, roads and pumps
			  ▪ Thickener

7.5 Initial Implementation

Due to commercial imperatives in developing a project of this magnitude, it needs to be implemented over time. The initial investment and development will be focused on those assets that will put the project in a position to partially fund the remaining development. This entails the design and construction of the initial components of the CPP (gold module, floatation plant, uranium plant, acid plant and a roaster), to retreat up to 1.5 Mt per month concurrently from the Driefontein 3 and 5 TSFs, Cooke 4 South TSF (1 Mt per month) and the Cooke TSF (0.5 Mt per month). Driefontein 3, 5 and Cooke 4 South TSFs will be mined sequentially over 11 years, whilst the Cooke TSF will be mined concurrent to these for a period of 16 years. The resultant tailings will be deposited onto the first stage of the RTSF.

A high grade uranium concentrate produced at the CPP will be transported to the Ezulwini Plant for the extraction of uranium and gold (0.5 Mt per month). The tailings from this process will be deposited on the operational Ezulwini North TSF. Figure 7-8 provides a visual overview of the project to be implemented in the initial phase, while Figure 8-1 provides a high-level overview of the Initial Implementation of the WRTRP process to be undertaken.

The CPP and RTSF are likely to be the two components of the WRTRP with the most significant potential environmental impacts. The CPP will be developed over a period of approximately 8 years. However, this application is for the entire CPP site i.e. three gold Modules, two Uranium plants, roasters and acid plant. The decision to take this approach, as opposed to authorising it in stages over 8 years, is to provide the regulators and the public with an impact assessment that takes the whole project into consideration.

The same logic is applied to the RTSF. It will be developed in two phases over the life of the WRTRP. However, the entire footprint is assessed from an environmental impact perspective. Thus, the cumulative impacts associated with the Ultimate Project can be assessed, as opposed to activity specific impacts, as well as avoiding incremental decision making by the authorities. Table 8-1 list the infrastructure, processes and related pumping activities that have to be considered from a radiological perspective during the Initial Implementation of the WRTRP. Activities, such as the supply of electricity are not listed, since it is not of any relevance to the potential radiological impact.

8 Environmental Baseline Conditions

The purpose of this section is to provide a summary description of the environmental baseline conditions. Within the conceptual assessment framework presented in Figure 5-1, this information provides input into understanding the release, subsequent distribution and accumulation of radioactivity released from the WRTRP into the environment and associated media. Several supporting specialist studies prepared as part of the EIA of the WRTRP were used as supporting documents for the environmental baseline description to ensure consistency. The reports related to the air quality, hydrology, hydrogeology, and socio-economic conditions (Digby Wells Environmental, 2015f; g; h; i) will be referenced for consistency and transparency.

Figure 8-1: Initial Implementation Process Summary

Table 8-1: Infrastructure, processes and pumping activities that have to be considered from a radiological perspective during the Initial Implementation of the WRTRP.

Category	Activity
Kloof Mining Right area	
Infrastructure	Pipeline routes (residual tailings)
	CPP incorporating Module 1 float and gold plants and No 1 uranium, roaster and acid plants and RTSF
	RTSF RWD and the AWTF
Processes	Abstraction of water from K10 shaft
	Disposal of the residue from the AWTF
	Gold, uranium and sulfur extraction at the CPP (tailings to RTSF)
	Water distribution at the AWTF for discharge or sale
Pumping	Pumping of up to 1.5 Mt per month of tailings to the RTSF
	Pumping water from the RTSF RWD to the AWTF
	Discharging treated water to the Leeuspruit
	Pumping residue from the AWTF to the RTSF
Driefontein Mining Right area	
Infrastructure	Pipeline routes (water, slurry and thickened tailings)
	WBT and BWSF
	Collection sumps and pump stations at the Driefontein 3 and 5 TSFs
Processes	Hydraulic reclamation of the TSFs at Driefontein 3 (including temporary storage of the slurry in a sump)
Pumping	Pumping water from K10 to the BWSF located next to the WBT
	Pumping water from the BWSF to the Driefontein TSFs that will be reclaimed
	Pumping slurry from the TSF sump to the WBT (for Driefontein 3 and 5 TSFs)
	Pumping the thickened slurry from the WBT to the CPP (2 pipeline route options)
Cooke Mining Right area	
Infrastructure	Pipeline Routes (water, slurry and thickened tailings)
	Cooke and NBT thickener
	Collection sumps and pump stations at the Cooke TSF
Processes	Abstraction of water Cooke 1 and 2 and Cooke No. 4 shaft
	Hydraulic reclamation of the Cooke TSF (including temporary storage of the slurry in a sump)
Pumping	Pumping 0.5 Mt per of tailings from the Cooke TSF to the Cooke thickener
	Pumping from the Cooke thickener to the CPP via Ezulwini
Ezulwini Mining Right area	
Infrastructure	Ezulwini floatation plant
Processes	Uranium extraction at Ezulwini (tailings to Ezulwini North TSF)
Pumping	Pumping water from the Pieter Wright Dam to Cooke 4 South TSF
	Pumping tailings from Cooke 4 South TSF to the CPP
	Pumping slurry from Ezulwini plant to Ezulwini North TSF

8.1 Climate and Meteorological Conditions

The conditions presented here is based on the description provided in the air quality impact assessment report (Digby Wells Environmental, 2015h), which uses 3 years of MM5 data (2012 to 2014) from Lakes Environmental in Canada for the purpose of the assessment. The Pennsylvania State University / National Center for Atmospheric Research (PSU/NCAR) meso-scale model (known as MM5) is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict meso-scale atmospheric circulation. This data has been tested extensively and has been found to be extremely accurate. The data used for this purpose is a point near Westonaria (26.317775 S, 27.650683 E).

8.1.1 Temperature

Table 8-2 presents three-year average maximum, mean and minimum temperatures for the project area. The monthly maximum temperatures range from 8.8°C in July to 18.2°C in January, with monthly average ranging from 2.4°C in July to 13.2°C in January. (see Figure 8-2). Annual mean temperature for the WRTRP is given as 15.23°C.

Table 8-2: Monthly Average Temperature Values

Temp(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Monthly Max.	18.2	18.2	17.9	14.9	13.5	11.4	8.8	14.1	15.3	16.0	17.2	17.3	15.23
Monthly Mean	13.2	12.8	11.6	6.9	4.8	3.2	2.4	4.0	7.4	9.1	9.5	12.4	8.10

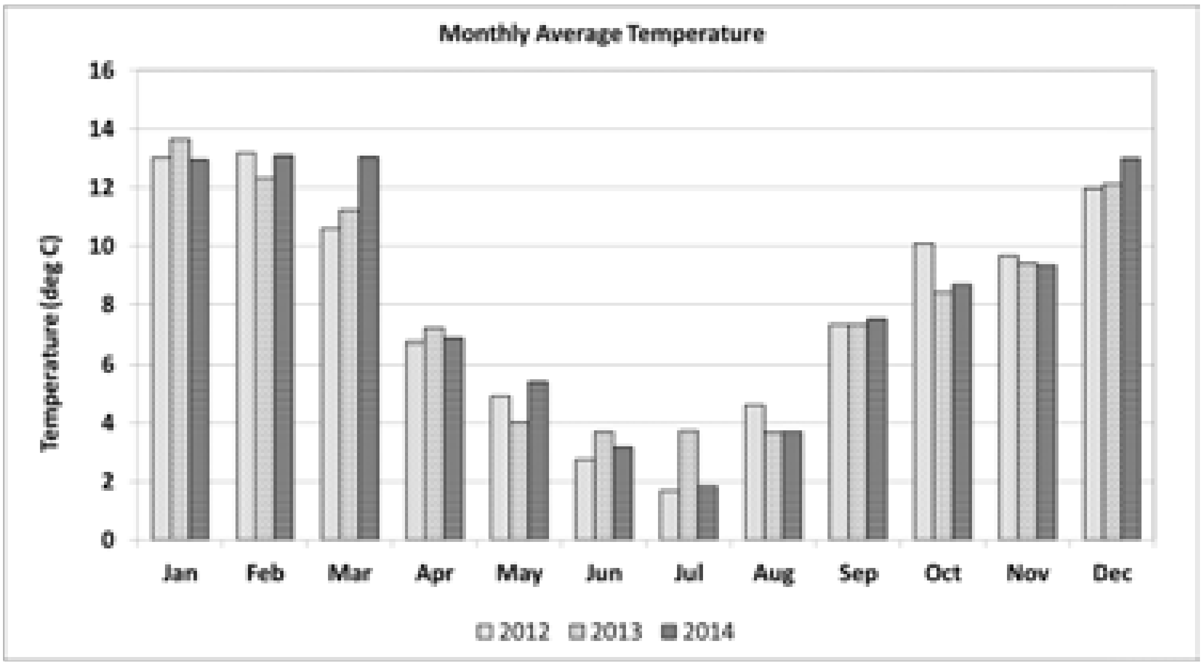

Figure 8-2: Monthly Average Temperature for 2012 to 2014.

8.1.2 Relative Humidity

The data in Table 8-3 is representative of the relative humidity for the WRTRP area. The annual maximum, minimum and average relative humidity is given as 66.4%, 61.6% and 63.8%, respectively (see Figure 8-3). The daily maximum relative humidity remains above 60% for most of the year, and range from 57.9% in November to 74.2% in March. The daily minimum relative humidity on the other hand is above 56% for the whole year, with the highest minimum (67.2%) observed in June and the lowest (55.6%) occurring in November.

Table 8-3: Monthly Average Relative Humidity Values

Relative Humidity (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Monthly Max.	67.1	65.6	74.2	63.3	64.0	72.2	69.9	67.7	67.7	64.0	57.9	63.8	66.4
Monthly Min.	62.1	60.9	60.6	62.5	61.5	67.2	63.0	63.6	61.8	60.8	55.6	59.1	61.6
Monthly Ave.	64.5	63.1	66.5	62.8	62.6	69.1	66.7	65.2	64.1	62.0	56.5	62.2	63.8

8.1.3 Precipitation

Figure 8-4 presents the total monthly precipitation for 2012 to 2014, while Table 8-4 presents the total monthly and average precipitation values. The annual total maximum and average are 1065 mm and 591 mm, respectively.

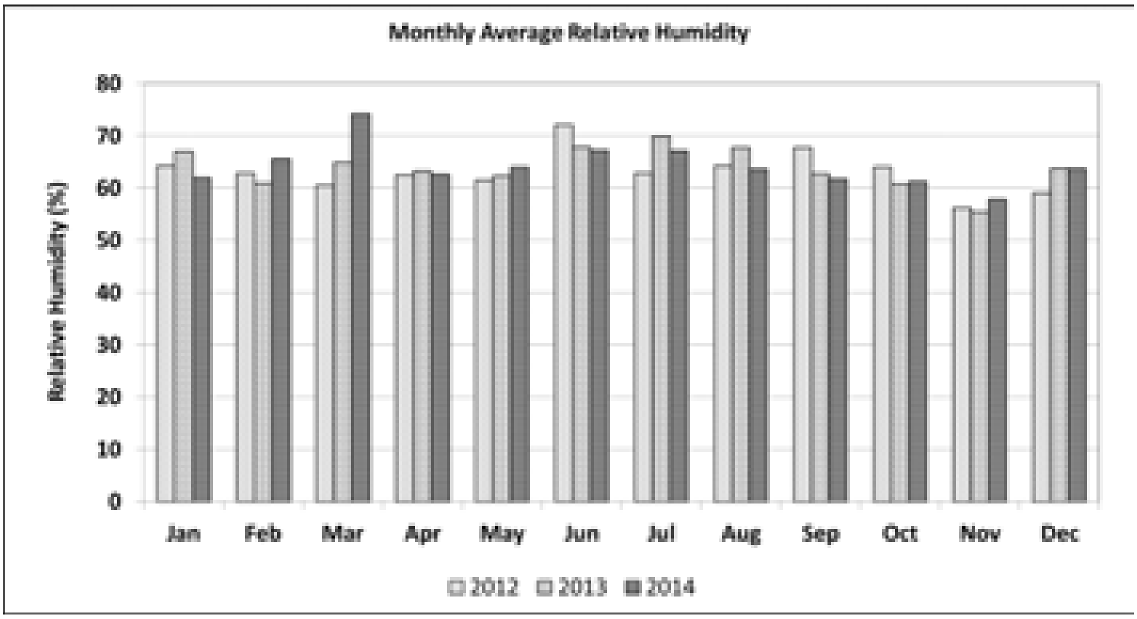

Figure 8-3: Monthly Average Relative Humidity for 2012 to 2014.

8.1.4 Evaporation

As shown in Table 8-5, the annual averages for maximum, minimum, and mean monthly evaporation rates for the Westonaria area for the period 1957 to 1987 (see Figure 8-5) are 263 mm, 113 mm and 178 mm, respectively. The highest monthly maximum evaporation (322 mm) occurred in October and the lowest of 68 mm in April. The monthly minimum evaporation ranges between 68 mm (April) and 180 mm in October.

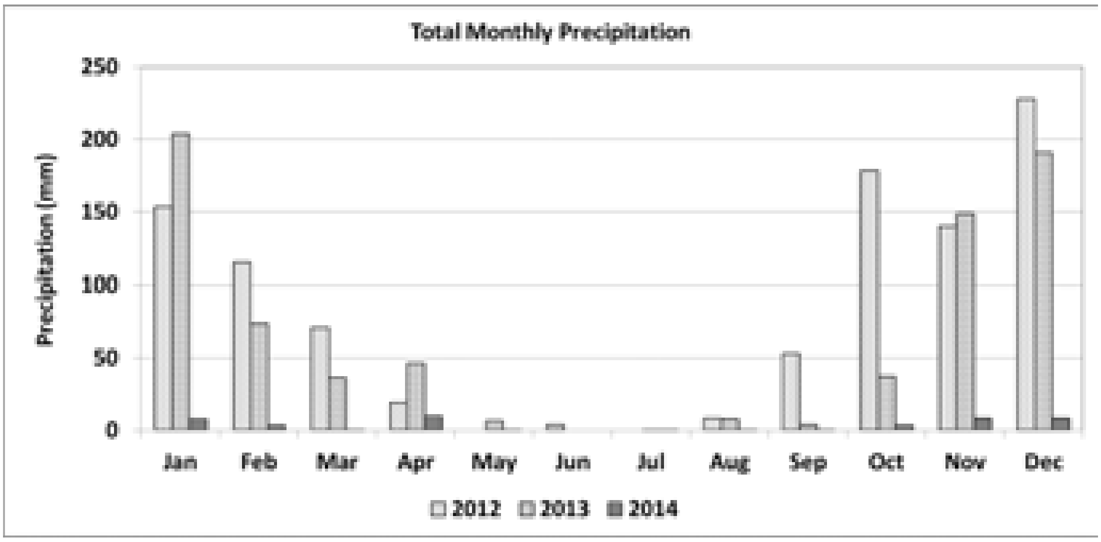

Figure 8-4: Total Monthly Precipitation for 2012 to 2014.

Table 8-4: Total Monthly and Average Precipitation Values.

Precipitation (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Total Monthly Rainfall (Max).	204.2	115.1	70.9	46.2	6.9	4.1	0.5	8.6	53.1	178.3	148.6	228.1	1065
Average Total Monthly Rainfall	122.0	64.1	35.8	25.1	2.6	1.4	0.3	5.8	19.2	72.9	99.1	142.5	591

Table 8-5: Monthly Evaporation Rates for Westonaria.

Evaporation (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Monthly Max.	289	262	224	190	223	244	257	261	288	322	277	320	263
Monthly Min.	88	120	93	68	79	70	85	111	155	180	178	128	113
Monthly Mean	206	177	171	141	124	109	126	170	224	253	224	212	178

8.1.5 Wind Field

Wind roses comprise 16 spokes that represent the directions from which winds blew during the specific period. The colours reflect the different categories of wind speeds. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories.

Figure 8-6 presents the spatial and annual variability in the wind field for the proposed project area calculated from the modelled data. The predominant winds are coming from north northeast and north, accounting for 18.9% and 16.7%. Winds from the NE sector dominated the wind regime. Wind speed greater that ≥ 5.4 $m.s^{-1}$ occurred for about 17.3% throughout the period. Secondary winds were also observed from the north northwest (10%)

and northeast (8%). Average wind speed was 3.86 m.s[-1]. Wind class frequency distribution per sector is given in Figure 8-7 and Table 8-6.

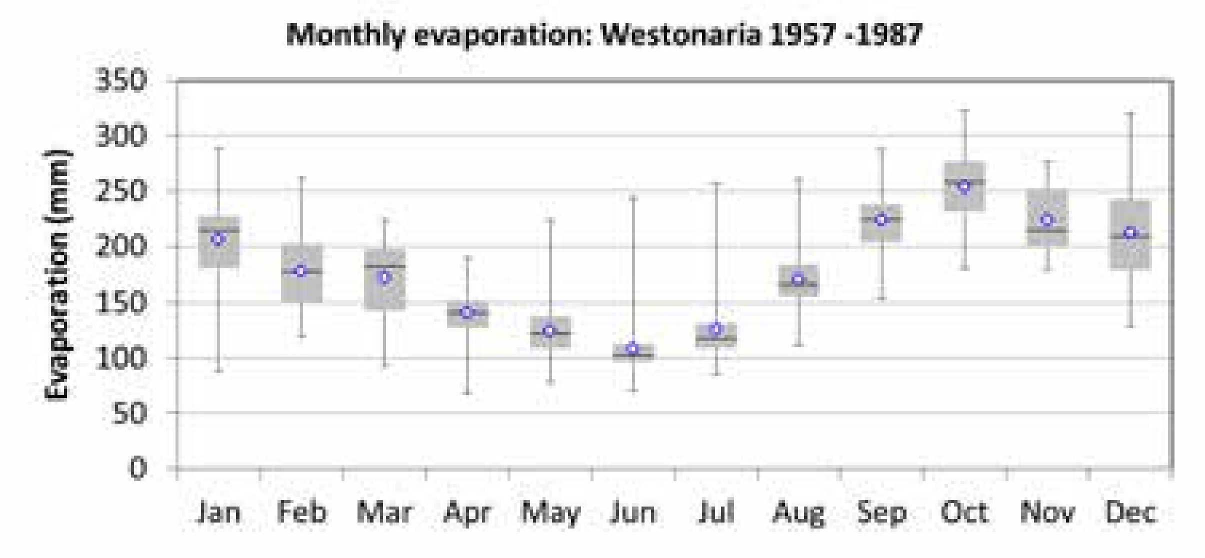

Figure 8-5: Monthly evaporation for Westonaria S-Pan Evaporation Station (1957 – 1987) (Source: South African Weather Service).

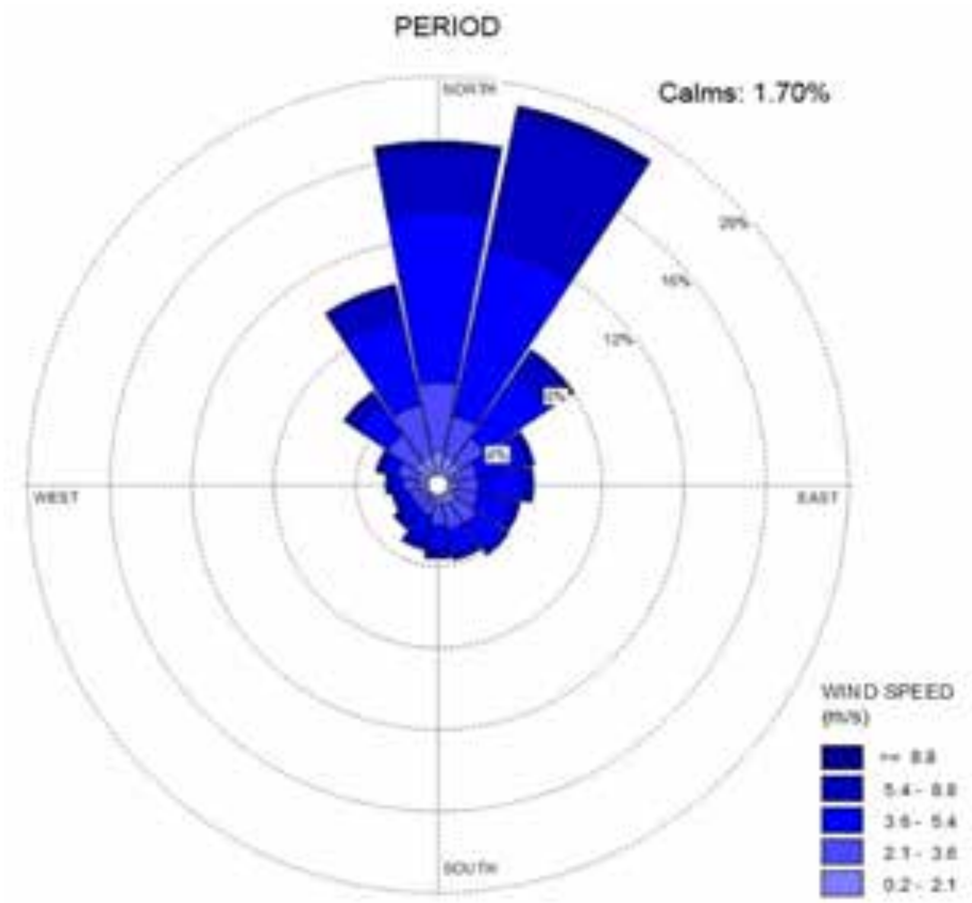

Figure 8-6: Surface Wind Rose for Sibanye Project Area.

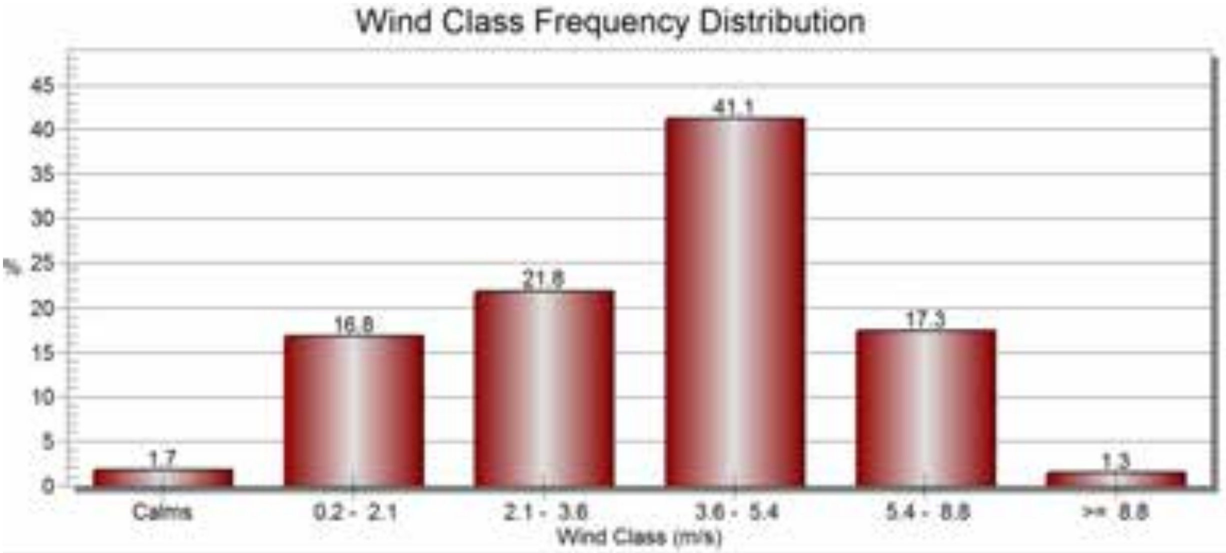

Figure 8-7: Wind Class Frequency Distribution.

Table 8-6: Wind Class Frequency Distribution per Direction.

No.	Directions	0.2 -2.1	2.1 -3.6	3.6 -5.4	5.4 -8.8	>= 8.8	Total (%)
1	N	1.6	3.4	8.4	3.1	0.4	16.8
2	NNE	1.5	2.0	8.4	6.6	0.4	18.9
3	NE	1.3	1.5	3.8	1.4	0.1	8.0
4	ENE	0.8	1.2	2.4	0.4	0.0	4.8
5	E	0.9	1.0	2.2	0.5	0.0	4.7
6	ESE	0.8	1.2	1.7	0.4	0.0	4.1
7	SE	1.1	1.2	1.6	0.3	0.0	4.2
8	SSE	1.0	1.2	1.2	0.3	0.0	3.8
9	S	0.9	1.0	1.1	0.5	0.1	3.6
10	SSW	0.7	0.8	1.2	0.5	0.0	3.2
11	SW	0.6	0.8	0.8	0.4	0.0	2.6
12	WSW	0.8	0.7	0.6	0.2	0.0	2.3
13	W	1.0	0.7	0.6	0.2	0.0	2.6
14	WNW	1.0	1.0	0.8	0.3	0.0	3.1
15	NW	1.3	1.6	1.8	0.7	0.1	5.6
16	NNW	1.5	2.5	4.4	1.5	0.2	10.0
Sub-Total		**16.8**	**21.8**	**41.1**	**17.3**	**1.3**	**98.3**
	Calms						1.7
	Missing/Incomplete						0
Total							**100**

The diurnal patterns during the night, morning and evening hours were somehow similar, with the dominant winds coming from the north, north northeast and north northwest (see Figure 8-8). The seasonal patterns show spring season to have been dominated by winds from the N (17%), NNE (15%) and NNW (11%) respectively.

Figure 8-9 shows the different seasons and the dominant wind patterns observed. In autumn, winds from the north northeast dominated (15%), with north being 14% and north northwest 11%. Winds >5.5 $m.s^{-1}$ accounted for 9.5% of the time, with an average wind speed of 3.25 $m.s^{-1}$. Spring was dominated by winds from north northeast (22%), and north (18%). Wind speed greater than 5.4 $m.s^{-1}$ occurred for 27.8% of the time (the highest for the different seasons). Wind >8.8 $m.s^{-1}$ accounted for 2.7% of the time. In summer, the dominant winds were observed from the north (11.7%). The winter season is dominated by wind blowing from the north (~20%) and north northeast (15.8%). Wind speed >5.4 $m.s^{-1}$ occurred for 20.3% of the time and winds in the range >8.8 $m.s^{-1}$ 2.3% of the time.

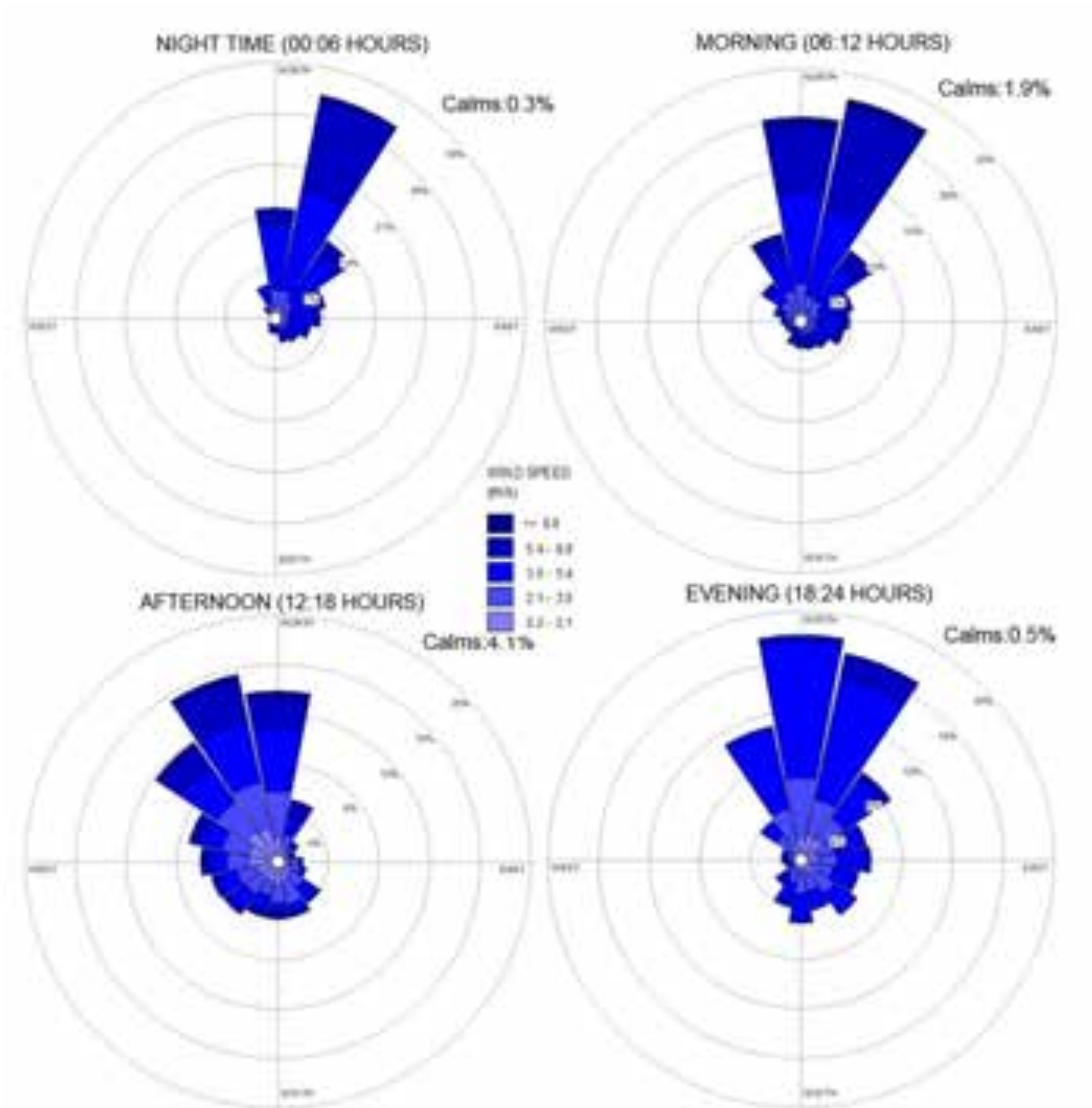

Figure 8-8: Diurnal variation of winds at night 00:00 – 06:00 (top right), morning 06:00 – 12:00 (top left), afternoon 12:00 – 18:00 (bottom left) and evening 18:00 – 24:00 (bottom right).

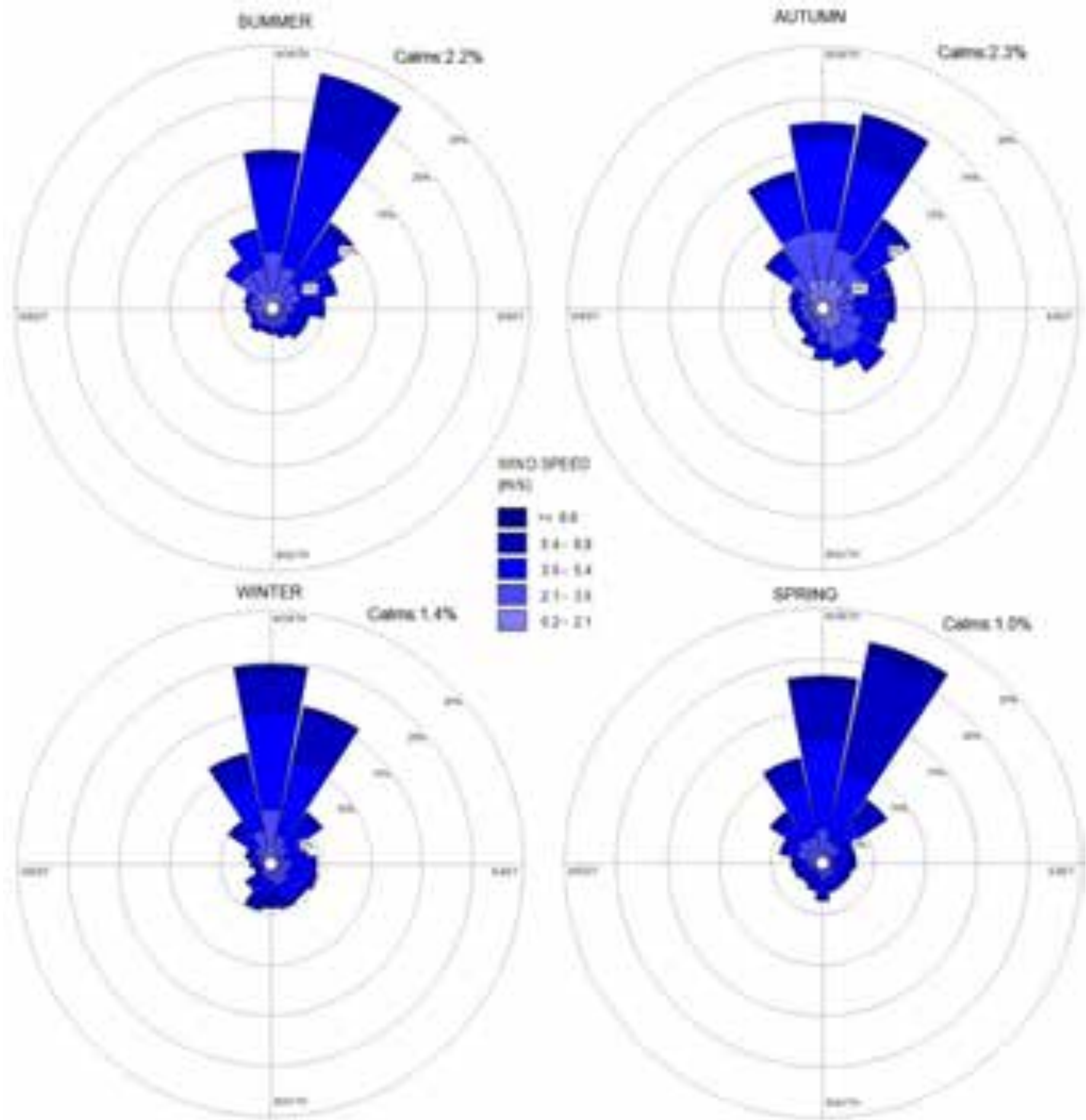

Figure 8-9: Seasonal variation of winds in summer (Dec – Feb), autumn (March – May), winter (Jun – Aug) and spring (Sep – Nov).

8.2 Topography

Viewed on a regional scale, the topography of the area is relative flat to undulating, but are characterised by a number of significant topographical features, like high ridgelines and valleys that appear prominent in the landscapes. The most significant of these is the Gatsrand, which stretches from east to west across the study area.

The elevation ranges from 1630 mams just north of the Cooke TSF, to 1670 mamsl in the vicinity of the Cooke 4 South TSF, before rising to 1780 mamsl over the Gatsrand. From the Gatsrand the elevation drops to in the order of 1520 mamsl in the vicinity of the RTSF site. The elevation north of the Gatsrand in the vicinity of the Driefontein No. 3 and Driefontein No. 5 TSFs are in the order of 1600 mamsl, sloping gently towards the Wonderfontein Spruit in the north.

8.3 Geology

The regional geology of the area is illustrated on the 1:250 000 Geology Map 2626 West Rand series, published by the Council for Geoscience. The surface geology comprises of Pretoria Group lithologies of the Transvaal Supergroup, of the Vaalian Erathem. The Pretoria Group sediments comprise of shale, slate, quartzite, siltstone and conglomerate of approximately 2 200 million years of age. The Pretoria Group lithologies form prominent east-west trending ridges in the vicinity of the study area. Diabase sills of a younger geological age (Monkolian 1 000 to 2 050 million years) are intruded into the Pretoria Group sediments (Digby Wells Environmental, 2015g).

Outcrops of dolomites of the Chuniespoort group (Transvaal Supergroup), which overlies the Witwatersrand Supergroup, occur over extensive areas of the goldfields. The dolomitic sequence is significant in terms of water resources in South Africa as it is a major aquifer, contributing to South Africa’s water resources and is highly susceptible and vulnerable to contamination (Digby Wells Environmental, 2015g). This is then also one of the main considerations for initiating the WRTRP, since some of the historical TSFs are located on dolomites, which may, under certain conditions, become unstable, form sinkholes, and have the potential to contaminate the underlying aquifer. Figure 8-10 shows that the historical TSFs can thus be divided into two groups based on the foundation geology (Digby Wells Environmental, 2015g):

- The first group consists of TSFs that are completely or partially located on dolomite. These are:
  - All of the TSFs within the Western Block except Driefontein No. 5; and
  - All of the TSFs within the Northern Block.
- The second group consists of TSFs sitting on the Transvaal shale and quartzite. The dolomite is at least 100 m below the surface and is not in direct contact with the TSFs:
  - All of the TSFs within the Southern Block; and
  - Driefontein No. 5 in the Western Block.

8.3.1 Dolomitic areas

According to Digby Wells Environmental (2015g), four of the five TSFs in the Western Block are situated directly on dolomitic outcrops. The exception is Driefontein No. 5, which is situated on the Pretoria Supergroup and that directly overlies the same dolomite on which the other TSFs are situated. To allow for safe mining operations, the area have been dewatered in the past, which resulted in a number of sinkhole formations. The thickness of the dolomites ranges from 0 m where the dolomitic bedrock outcrops to 200 m below ground surface. The dolomitic rocks contain vast quantities of water. In the Northern Block, the Cooke TSF, Venterspost North TSF and Venterspost South TSF all lie entirely on the Malmani Dolomite of the Transvaal Supergroup, while the Millsite and Ezulwini TSFs are partially on the dolomite and partially on the shales and quartzites of the Transvaal sequence that overlie the dolomite.

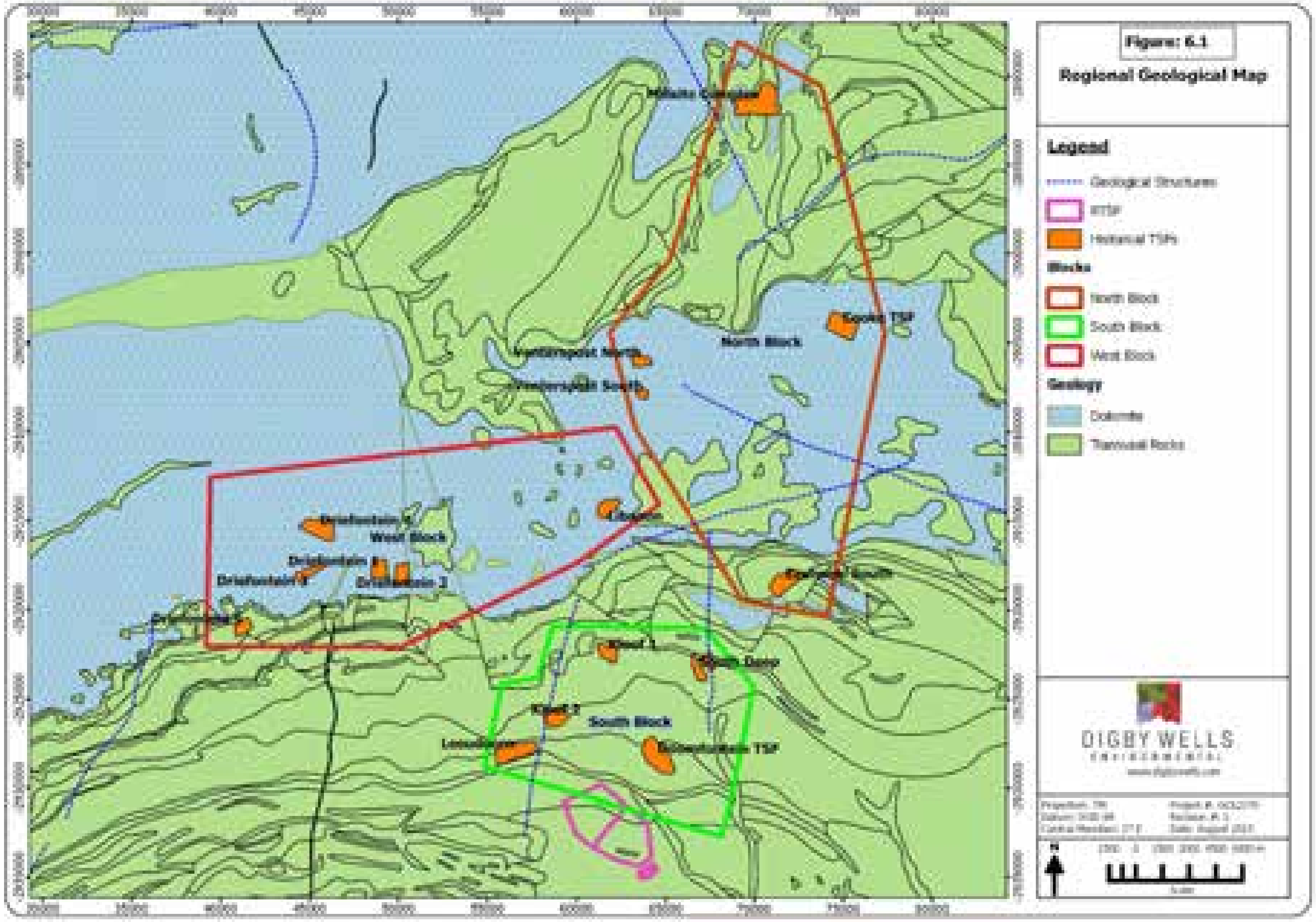

Figure 8-10: Regional geological map (Digby Wells Environmental, 2015g).

The dolomite in this zone contains lenses and layers of chert. The dense, hard and fine-grained chert tends to stand out in relief. Chert replaces carbonate material. The Karoo Supergroup includes dolerite dykes, geological features, which cut through the dolomites around area forming a series of fault and dyke banded blocks.

8.3.2 Non-Dolomitic Areas

The Southern Block is situated directly north of the RTSF site. According to the 1:250 000 geological map (2525 West Rand), the geology of the Southern Block is generally gentle (10 - 20º) south dipping Magaliesberg, Silverton, Daspoort and Hekpoort Formation units, which is part of the Pretoria Group of the Transvaal Supergroup.

The Pretoria Group comprises predominantly mud rocks alternating with quartzitic sandstone, significant inter-bedded basaltic-andesitic lavas, subordinate conglomerates, diamictites and carbonate rocks, all of which have been subjected to low grade metamorphism. Several structures traverse the area in a dominantly N-NE to S-SW trend (Digby Wells Environmental, 2015g). The gold mining activities generally occur below the dolomitic rocks, which underlie the Ventersdorp lavas and the Witwatersrand succession. As the fissure water remains locked within the dolomitic zone, the shallow aquifer is not impacted by the underground workings/activities.

8.3.3 Area in the Vicinity of the RTSF Site

Figure 8-11 presents the local site geology in the vicinity of the RTSF site. The area is underlain by a gentle sloping stratum, generally dipping to the south at 10 to 20º. The stratigraphic succession along three deep exploration boreholes (more than 3000 m deep) in a north-south geological cross section is illustrated in Figure 8-12 (Digby Wells Environmental, 2015g). The oldest rocks of the Central Rand, Klipriviersberg and Chuniespoort Groups (3100-2200 My) appear on surface to the north of the area, with progressively younger rocks outcropping in the south. Extensive diabase sill intrusions, as characterised by its highly positive magnetic signature in the aeromagnetic survey, is evident as intrusions in the Silverton shale and Timeball Hill siltstone-shale sequences.

Two north-south striking negative magnetic diabase dykes (Gemsbokfontein No.1 and No. 2 dykes), associated with the Pilanesberg tectonic event (1300 My), pass approximately 1 km east of the RTSF footprint area (see Figure 8-11). The fold hinge zone that crosses along the Doornfontein TSF is expected to curve and strike approximately 3.7 km east of the RTSF.

The geological profiles of the boreholes drilled in the area show that on a more local scale, the footprint area of the RTSF is underlain (from north to south) by Strubenkop shale, Daspoort quartzite and Silverton shale units of the Pretoria Group (2200-2050 My). In addition to shale, diabase sills were also encountered in some boreholes. No dolomite was encountered in any of the boreholes. Based on deep exploration boreholes drilled at the Goldfields TSF site, the dolomite is expected to be more than 1500 km underneath the RTSF.

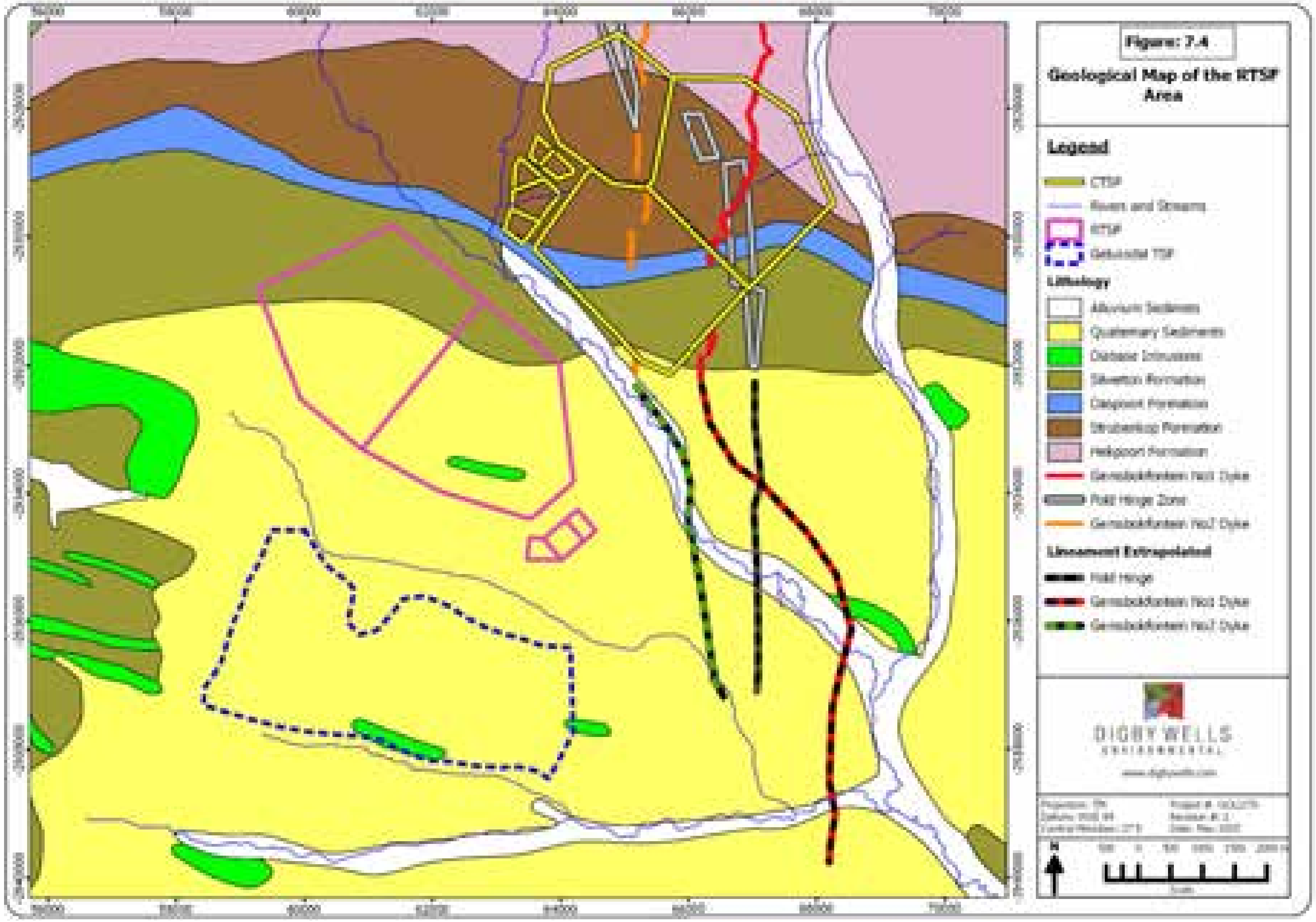

Figure 8-11: Site geology in the vicinity of the RTSF site (Digby Wells Environmental, 2015g).

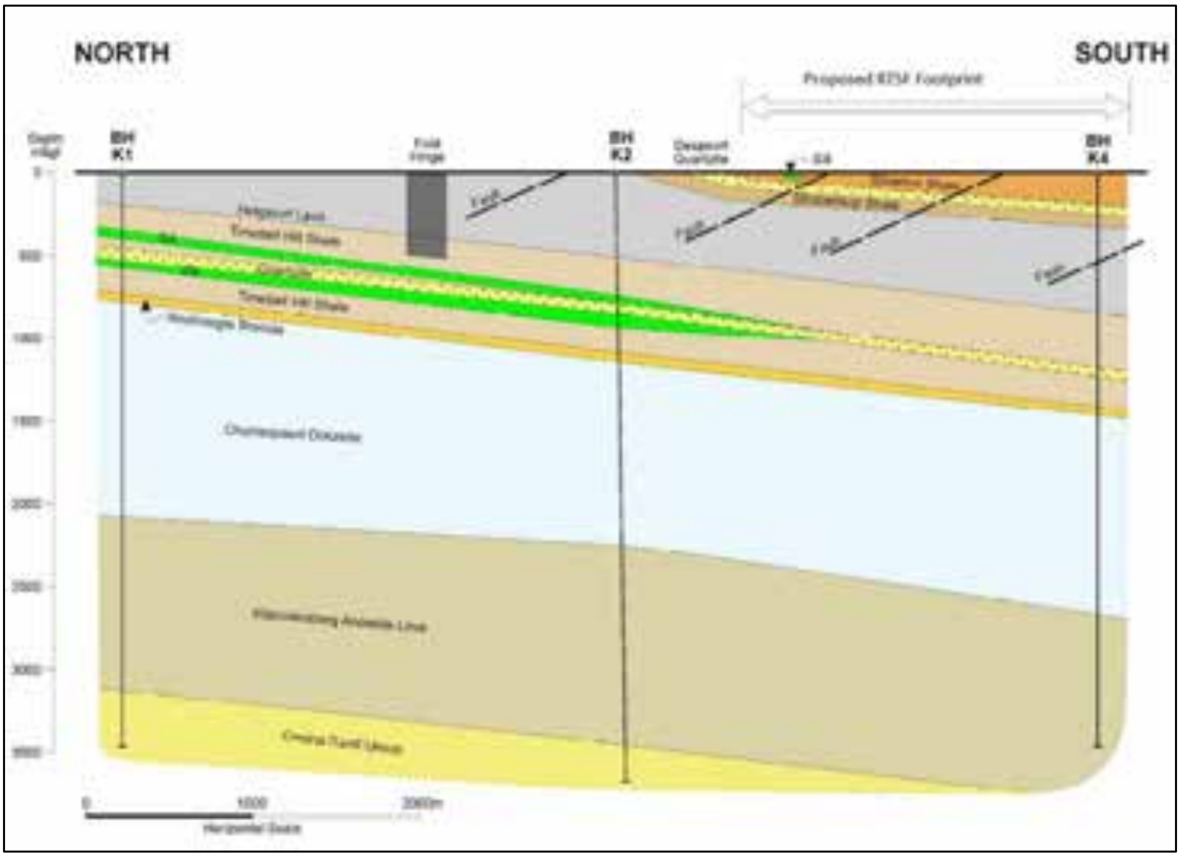

Figure 8-12: Geological cross-section over project area (Digby Wells Environmental, 2015g).

The depth of weathering over the shale unit is of the order of 20 m to 26 m, with the deepest weathering along the watercourse. The depth of weathering over the diabase is approximately 20 m to 25 m, with the deepest weathering also encountered along the watercourse.

8.4 Hydrogeology

The historical TSF areas are widespread, with the result that the local hydrogeological conditions are expected to vary significantly between the four Mining Right areas. One of the significant benefits of the WRTRP is that these TSFs, once retreated and subject to clean-up and rehabilitation of the foot print area, will be eliminated as potential sources for groundwater contamination. This will apply, in particular, to the TSFs located on dolomites.

Presented below is a brief overview of the hydrogeological conditions of the areas located on dolomitic and non-dolomitic areas, with a more detailed discussion of the RTSF area. The conditions presented here is based on the description provided in the groundwater impact assessment report (Digby Wells Environmental, 2015g).

8.4.1 Dolomitic Areas

Local confined to semi-confined conditions exist where the dolomite is overlain by impermeable strata such as Ventersdorp lavas or Karoo sediments. Water levels in the shallow aquifers are different from the dolomite areas, if they are separated by an impermeable layer.

Groundwater levels in dolomite aquifers are controlled by topography, permeability, mine compartmentalisation, recharge and dewatering. Groundwater levels in the shallow aquifer zones tend to mimic the topography, while more complex groundwater flow paths exist in the deep dolomitic and fractured aquifers.

Pre-mining water levels were shallow and ranged from 1 to 30 m below surface (average 14.49 m). Dolomitic springs feeding into streams were common across the dolomitic areas, but are now dry due to the dewatering activities of the underground mining.

Generally, the groundwater table in the dolomitic aquifer does not mimic the topography. The groundwater table is relatively flat and influenced by compartmentalisation. Highly variable water level measurements were taken over short distances indicating the presence of groundwater barriers. Gold mining requires significant dewatering to keep the mine workings dry and safe and water levels are currently still being kept between 800 and 1200 metres below ground level (mbgl).

The historical TSFs that are located directly on dolomite outcrops drain into the dolomitic system as none of them is lined. Due to the dewatered nature of the dolomite, the low pressure within the dolomite encourages drainage from these TSFs.

Borehole yields in the shallow aquifer have been recorded between 0.5 and 2 $L.s^{-1}$. In the dolomitic aquifers, borehole yields are likely to exceed 5 $L.s^{-1}$.

8.4.2 Non-Dolomitic Areas

The aquifers in this area can be divided into three distinct aquifers (Geohydrological Map Series, 1:500 000 Johannesburg), namely (Digby Wells Environmental, 2015g):

- Shallow weathered aquifer: within the weathered formation as a result of increasing secondary porosity, located 5 to 10 mbgl, and is limited and variable in extent.
- Deeper semi-confined fracture zone aquifer: within the Pretoria Group sediments, overlain by weathered shale layers, and adjacent to dykes and faults.
- Deep confined compartmentalised dolomitic (karst) aquifer (Malmani Dolomite); comprised of interconnected joints, weathered dykes contacts, fault planes, fractures, cavities and solution channels, within the dolomite beneath the thick cover of the Pretoria Group sediments.

The borehole yields range between 0.5 $L.s^{-1}$ and 2 $L.s^{-1}$ (DWS, 1:500 000 Geohydrological Map Series), while the aquifer(s) are classified as having a moderate to high susceptibility and vulnerability rating, based on the 1:3 000 000 Aquifer Vulnerability and Susceptibility Map Series.

Groundwater levels in the aquifer(s) tend to mimic the topography, while more complex groundwater flow paths are associated with deep confined fractured aquifer and dolomitic zones.

8.4.3 Area in the Vicinity of the RTSF Site

8.4.3.1 Groundwater Level and Flow Direction

Groundwater levels from 181 boreholes located within a 10 km area was used to evaluate the water level and flow direction. A comparison of the water elevation with topography shows a good correlation of 97.11% (see Figure 8-13).This means that groundwater flow mimics the topography and is towards surface water drainage courses as base flow, generally from the northwest to southeast. This is confirmed in Figure 8-14, which shows the groundwater gradient and flow direction derived from the hydrocensus boreholes.

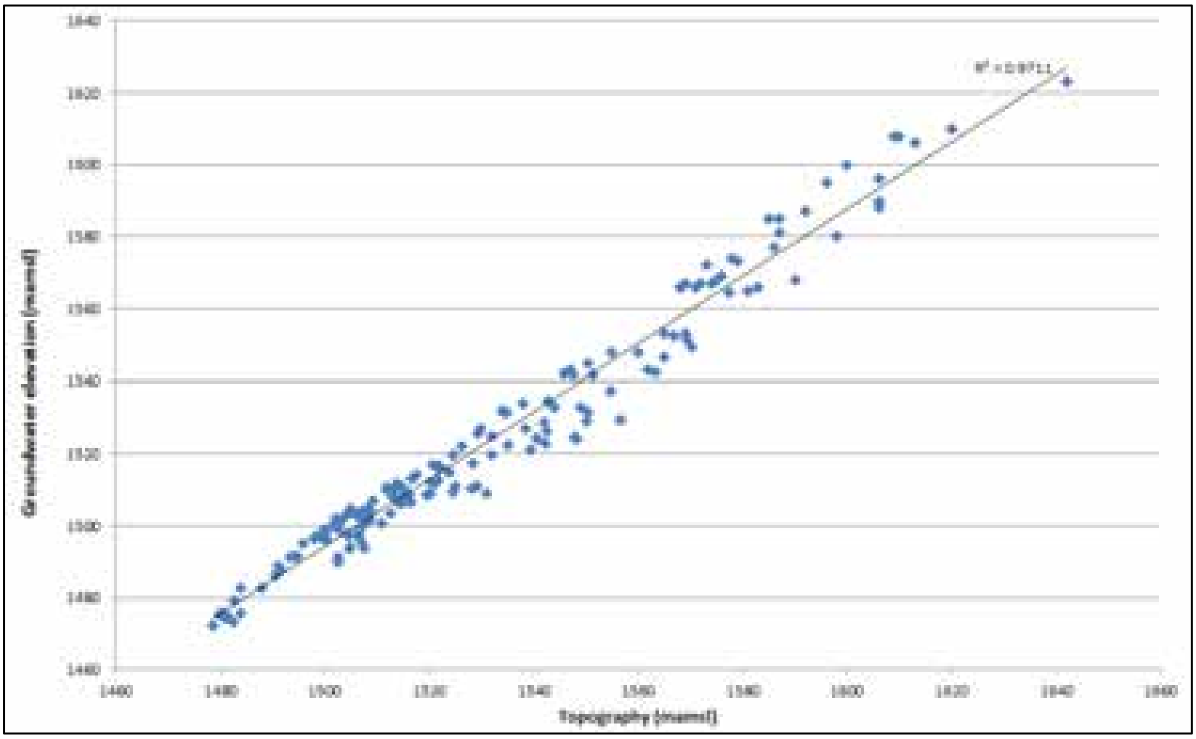

Figure 8-13: Correlation between topography and groundwater level

8.4.3.2 Aquifer Properties

The aquifers underlying the RTSF site is characterised as low yielding, semi-confined weathered (and fractured) aquifer systems, mostly composed of the Pretoria Group geology. This is based on the hydrogeological borehole information obtained from the borehole drilling and aquifer testing of the boreholes within a 5 km of the RTSF.

Comparison of groundwater levels with the water strikes indicates that the depth of water strikes is in most cases below the measured groundwater levels, which is indicative of confining groundwater flow conditions.

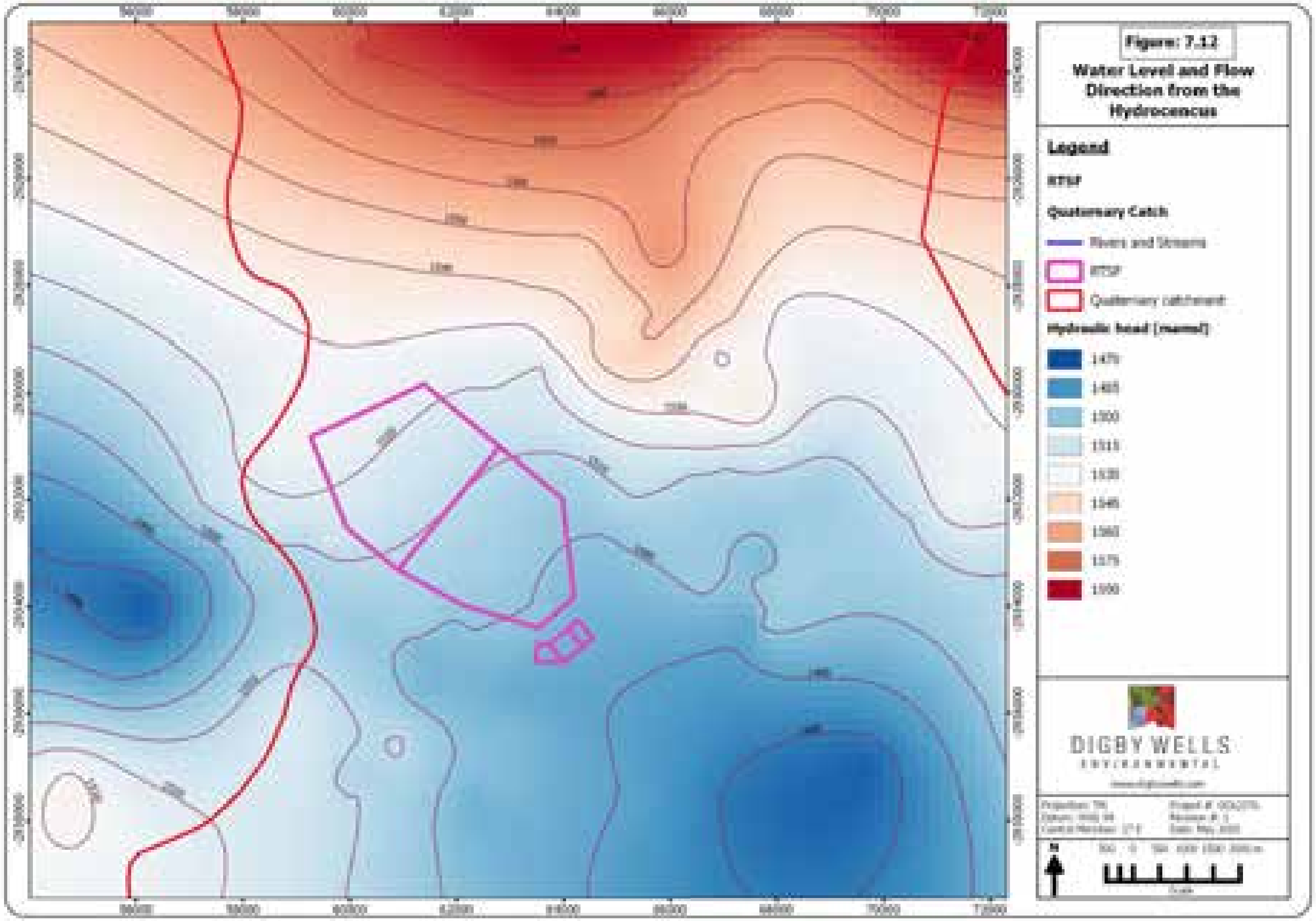

Figure 8-14: Water level and flow direction derived from the hydrocensus boreholes (Digby Wells Environmental, 2015g).

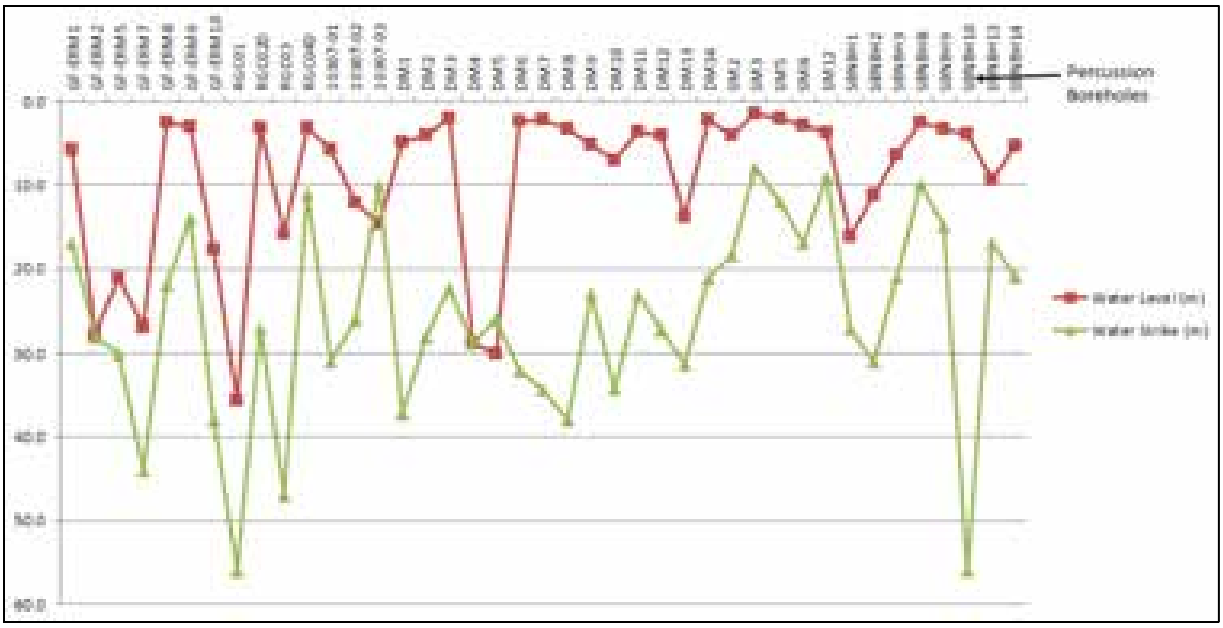

Figure 8-15: Correlation between water strike and water level

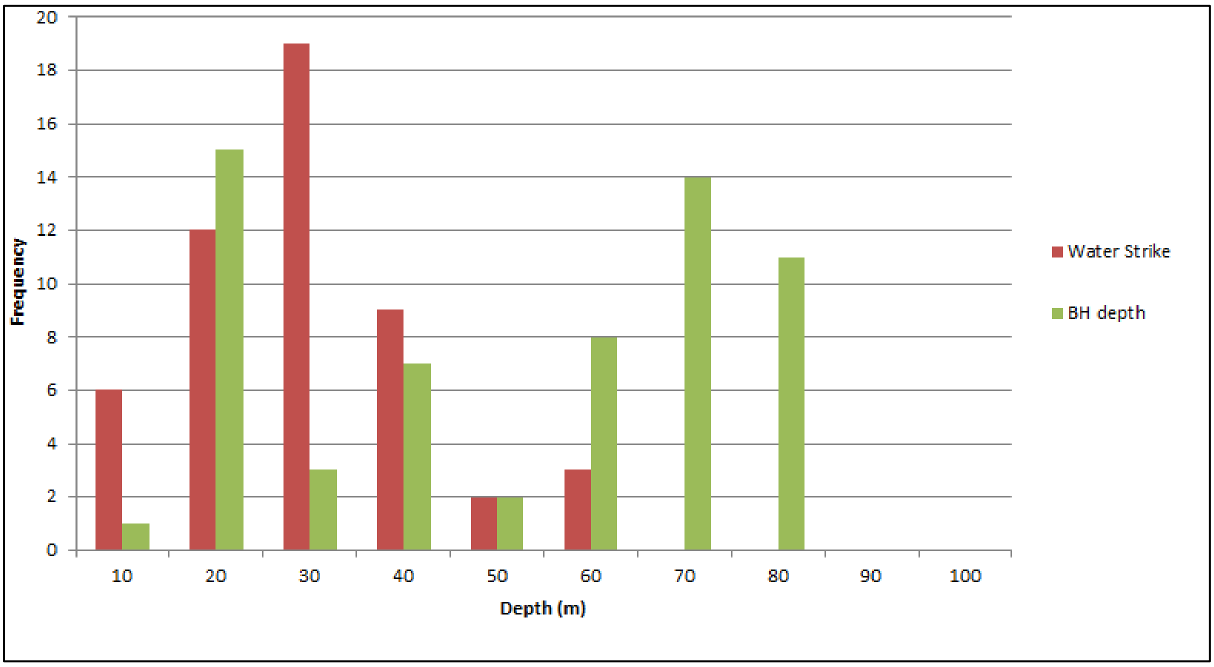

Figure 8-16: Water strike frequency

Figure 8-15 shows that the difference varies from a few centimetres to 52 m. However, a continuous confining layer appears to be absent and the aquifers underlying the site have been classified as being semi-confined. Figure 8-15 indicates that the static water level in boreholes DM5 and 10307-03 are below the water strike positions. This is probably due to small scale fractures below the major water strike positions, through which water seeps away from the boreholes either laterally or vertically.

8.4.3.3 Aquifer Layers and Thickness

The frequency of the water strikes observed is illustrated in Figure 8-16. The water strikes are encountered at depths between 10 and 60 m below ground level (mbgl), with the majority occurring between 20 and 40 mbgl.

Half of the 28 percussion boreholes drilled by Golder are shallow (12 to 24 m deep) and the remaining 14 are deep (70 m). As stated in the Golder (2009) report, the differences between the water levels of the shallow and deep boreholes are generally less than 0.1 m. This implies that there is no major head difference between the shallow and deep boreholes, which is a confirmation that they are intersecting the same aquifer.

The water qualities in the shallow and deep boreholes also display the character of recent recharge from rainfall, which is consistent with the connectivity between the two sets of boreholes. The connectivity of the two aquifers is also indicated by the aquifer testing where by pumping of deep boreholes will have an immediate influence on the shallow boreholes. This conceptual model is also consistent with that of the Goldfields boreholes, which are just on the northern boundary of the RTSF site. A blast curtain that will be excavated to a depth of 30 m from surface is one of the mitigation scenarios considered for the RTSF plume containment. To more accurately simulate the blast curtain, the aquifer has been subdivided in two layers with a thickness of 30 m each (Digby Wells Environmental, 2015g).

8.4.3.4 Aquifer Permeability

Aquifer tests were conducted during this study for rock permeability assessment. These results, together with historically evaluated permeability values in the vicinity of the RTSF are displayed in Figure 8-17.

The aquifers underlying the RTSF site are characterised by low hydraulic conductivity, ranging between 0.0002 $m.d^{-1}$ (Borehole SBNBH2) to 0.806 $m.d^{-1}$ (Borehole DM12), with a harmonic mean of 0.005 $m.d^{-1}$. This indicates that the groundwater flow rate is limited and the contamination plume from the RTSF will not migrate far from the RTSF footprint, even after mine closure. The plume will migrate very slowly, but high concentrations are expected to remain in the aquifer for a long time after loading has stopped.

The significantly higher permeability of 4.1 $m.d^{-1}$ was noted in borehole SNBBH3. This is suspected to be a local fracture zone that is not representative of the project area that can be considered as a potential upper limit of the permeable nature of the fractures.

8.4.3.5 Aquifer Storage

Determination of storativity is only required for the transient state simulation. The storativity values obtained from the aquifer tests during this study and the previous Golder study (2009) is listed in Table 8-7 and range between 0.002 to 0.784, with an average value of 0.155.

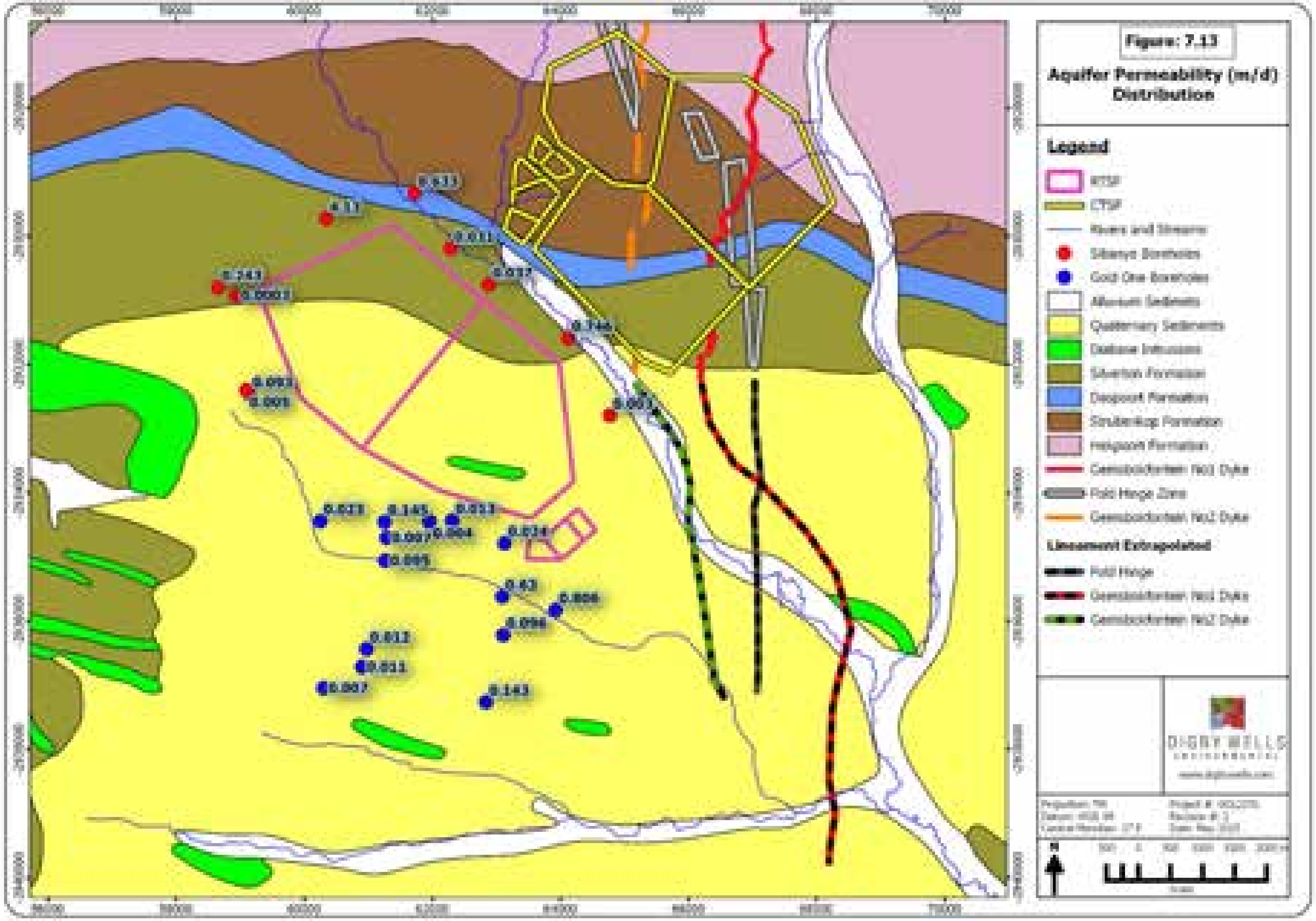

Figure 8-17: Aquifer permeability distribution (m/d).

Table 8-7: Hydraulic parameters of the boreholes in the RTSF area

BH	X	Y	K value	Storativity
DM1	60899	-2936717	0.011	0.019
DM10	62832	-2937268	0.143	
DM11	63089	-2935623	0.630	0.698
DM12	63921	-2935830	0.806	0.634
DM13	60300	-2937047	0.007	
DM14	60251	-2934442	0.023	0.019
DM2	60969	-2936437	0.012	0.014
DM3	61251	-2934456	0.145	0.137
DM4	61282	-2934702	0.007	0.012
DM5	61950	-2934447	0.004	
DM6	62305	-2934433	0.013	0.021
DM7	61262	-2935060	0.095	0.051
DM8	63123	-2934789	0.024	0.015
DM9	63102	-2936220	0.096	0.027
SBNBH1	58656	-2930795	0.243	0.473
SBNBH2	58935	-2930920	0.000276	
SBNBH3	60340	-2929726	4.13	0.016
SBNBH4	61724	-2929328	0.633	
SBNBH5	62284	-2930188	0.0308	
SBNBH7	62880	-2930754	0.037	
SBNBH9	64122	-2931591	0.746	0.055
SBNBH10	64767	-2932794	0.00321	0.784
SBNBH13	59143	-2932460	0.0934	0.0931
SBNBH14	59094	-2932402	0.00537	
SBNBH6A	62870	-2930754	1.3	0.00163
SBNBH8A	64193	-2931689	2.64	0.0021
SBNB11A	65126	-2934207	0.29	0.0083
SBNB12A	64612	-2935237	0.201	0.018

8.4.3.6 Contaminant Transport Parameters

In most cases, contaminant transport is driven by advection, i.e. groundwater flow is the main mechanism controlling the movement of solutes in groundwater. Advection implies that contaminants migrate at a rate similar to the groundwater flow velocity and in the same direction as the hydraulic gradient. Therefore, knowledge of groundwater flow patterns and hydraulic parameters can be used to predict solute transport under advection. Other parameters to consider include dispersion, diffusion, effective porosity, adsorption, and the specific yield.

Dispersion and Diffusion

Dispersion of contaminants in groundwater is also important in terms of contaminant transport. Dispersive transport is caused by the tortuous nature of pores or fracture openings that result in variable flow velocity distributions within an aquifer and movement of contaminants due to the difference in concentration gradient.

Dispersion has two components; longitudinal and transversal dispersivities. The longitudinal dispersivity is scale dependent and is usually approximately 10% of the travel distance of the plume. The transversal dispersivity is approximately 10% of the longitudinal dispersivity. The higher the dispersivity, the smaller the maximum concentration of the contaminant, as dispersion causes a spreading of the plume over a larger area.

The average distance of the TSF footprint to the nearby steams on the immediate north and south is approximately 500 m. If it is postulated that the streams are the main receptor of the contaminant plume, a longitudinal dispersivity of 50 m and a transversal dispersivity of 1 m is estimated. A diffusion coefficient of $1x10^{-5}\ m^2.day^{-1}$ was selected as acceptable for sedimentary rocks.

Effective Porosity and Specific Yield

The percentage of void volume that contributes to groundwater flow is expressed by the term porosity. Not all pores are interconnected and therefore cannot contribute equally to groundwater flow, leading to the derivation of the term “effective porosity”, used to express the interconnected void volume that effectively contributes to groundwater flow and therefore contaminant transport. The higher the effective porosity, the slower the contamination migration rate, because more pore voids have to be filled. The specific yield of a unit volume aquifer is the quantity of water that can be released or drained as a result of gravity. This implies that the specific yield is either equal or less than the effective porosity.

Based on the geological composition of the site, an effective porosity and specific yield of between 0.03 and 0.02 are applied across the entire model domain.

8.4.4 Groundwater Receptors

Since the groundwater flow is the main mechanism for the transportation of contaminants from the RTSF, it is not possible for the pollution plume to migrate towards the northwest (opposite to the groundwater flow direction). The main receptors that are at risk of contamination are those in the immediate vicinity of the RTSF (with a radius of 2 km), as well as those located down-gradient of it. The following groundwater receptors are expected to exist, that could potentially be exposed to contaminated groundwater derived from the RTSF:

- The Leeuspruit that is northwest of the RTSF;
- The non-perennial tributary of Leeuspruit that flows on the south side of the RTSF; and

- Boreholes associated with farms down-gradient of the RTSF, in the southeast direction.

8.5 Hydrology

South Africa is divided into 19 water management areas (WMA), each managed by its own water board. Each of the WMA is made up of quaternary catchments that relate to the drainage regions of South Africa. Each of the quaternary catchments have associated hydrological parameters including area, mean annual precipitation (MAP), mean annual evaporation (MAE), and mean annual runoff (MAR).

The conditions presented here is based on the description provided in the surface water impact assessment report (Digby Wells Environmental, 2015i)

8.5.1 Regional Hydrology

The WRTRP is situated in the Upper Vaal Water Management Area (WMA) 8 within quaternary catchments C23E, C23J, C23D, C22J and C22H.

Table 8-8 summarises the surface water attributes of the affected quaternary catchments , while Figure 8-18 presents a summary of the regional hydrological setting.

Table 8-8: Summary of the surface water attributes for quaternary catchments.

Quaternary Catchment	Total Area (km^2)	MAP (mm)	MAR (Mm^3)	MAE (mm)
C22H	454	639	8.38	1650
C22J	669	633	11.81	1650
C23D	510	664	9.12	1650
C23E	850	631	13.41	1675
C23J	890	620	18.49	1670

The C22H quaternary catchment area is 454 km^2 and has an MAR of 8.38 Mm^3. Runoff emanating from this quaternary catchment drains into a south westerly direction into the Klein Wes Riet Spruit, which in turn flows into the larger Riet Spruit.

The C23D quaternary catchment area is 510 km^2 and has an MAR of 9.12 Mm^3. Runoff emanating from this quaternary catchment drains in a south westerly direction into the Wonderfontein Spruit, which is the largest river in the quaternary catchment. The C23D quaternary catchment is a contributing catchment to C23E, therefore all runoff from C23D eventually drains to the catchment outlet of C23E.

The C23E quaternary catchment area is 850 km^2 and has an MAR of 13.41 Mm^3. Runoff emanating from this quaternary catchment drains in a south westerly direction *via* the Mooirivierloop. The C23E quaternary catchment includes urban areas which are greater than 5 km^2.

The C23J quaternary catchment area is 890 km^2 and has an MAR of 18.49 Mm^3. Runoff emanating from this quaternary catchment drains in a south westerly direction *via* the Loop Spruit. The Loop Spruit is the largest river within the quaternary catchment.

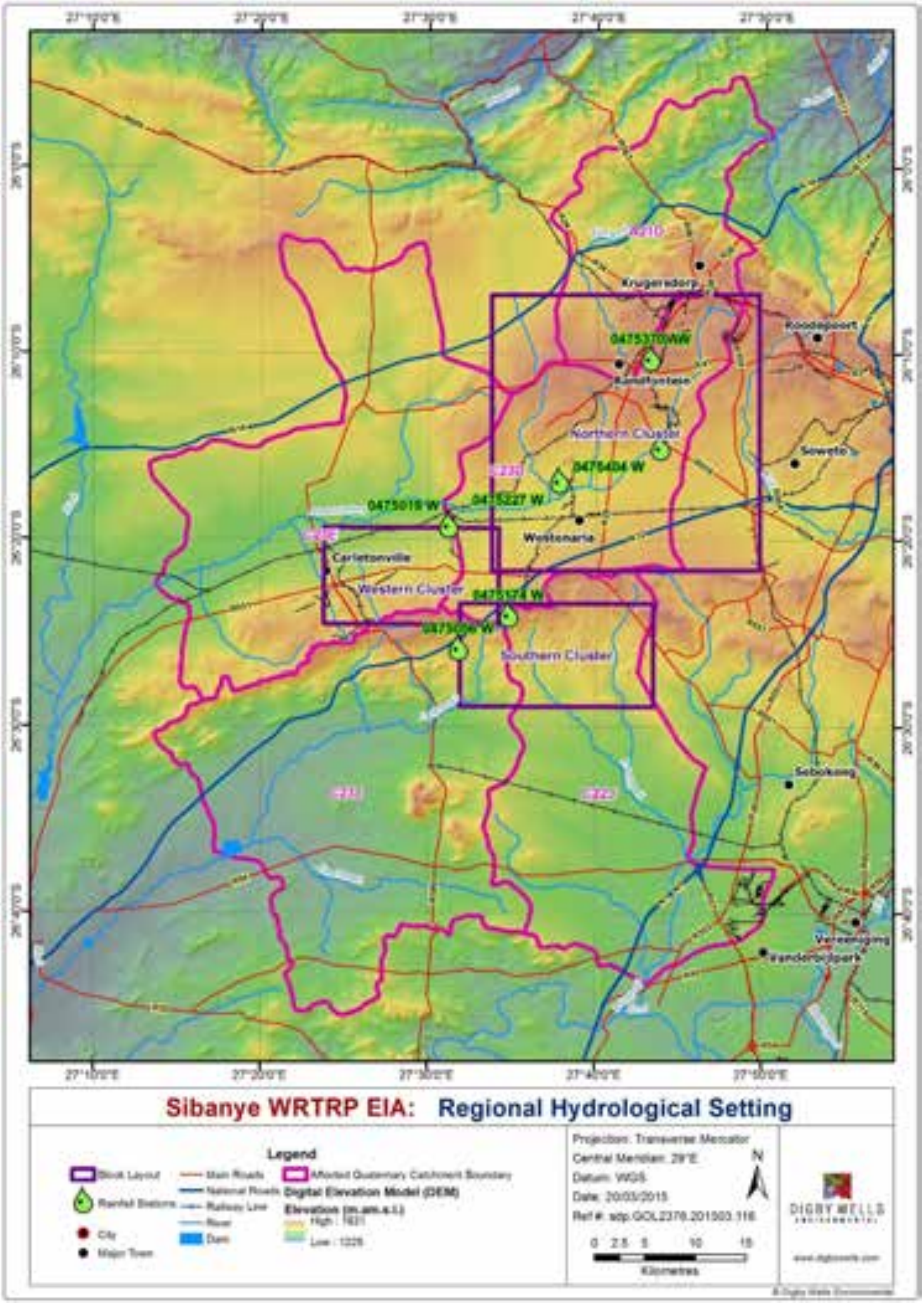

Figure 8-18: Regional Hydrological Setting

The C22J quaternary catchment area is 669 km^2 and has an MAR of 11.81 Mm^3. Runoff emanating from this quaternary catchment drains in a southerly direction *via* the Leeuspruit. The Leeuspruit is the largest river within the quaternary catchment.

8.5.2 Rivers and Drainage

There are a number of rivers draining the WRTRP area, which include the Mooirivierloop, Riet Spruit, Wonderfontein Spruit, Loop Spruit, Leeuspruit and the Klein Wes Riet Spruit, which are classified as perennial rivers, together with a few unnamed, non-perennial streams that form tributaries to these main rivers.

The Wonderfontein Spruit flows in a south westerly direction and eventually drains into the Mooi River at a point below the Muiskraal Dam, located west of the WRTRP area. This catchment has been changed as most of the normal flow from the Donaldson Dam is directed into a pipe known as the 1m pipe. Other flows from regional Waste Water Treatment Works (WWTW) and the K10 shaft also discharge into this pipe. This pipe takes these flows over a dolomitic area to reduce recharge and discharges at a point near Oberholzer. At this discharge point, the Driefontein Operations also discharges large amounts of pumped mine water.

The Leeuspruit is a tributary of the Riet Spruit, with the latter joining the Upper Vaal River system at the Vaal Barrage.

The Klein Wes Riet Spruit surface water runoff drains in a south easterly direction towards the Riet Spruit, with the latter joining the Upper Vaal River system at the Vaal Barrage.

The Loop Spruit forms part of the Mooi River catchment and flows into the Mooi River at Potchefstroom, located south west of the WRTRP area. All runoff drained by the Loop Spruit eventually reaches the Vaal River.

In summary, the Mooi Rivier and the Wonderfontein Spruit drain the northern catchment of the WRTRP area, whilst the Leeuspruit, Klein Wes Riet Spruit and the Loop Spruit drain the southern catchment of the WRTRP area.

8.5.3 Mean Annual Runoff

Based on GN 704[1] requirements, all runoff emanating from dirty water areas such as mine infrastructures including the RTSF area, sumps and CPP needs to be contained within these areas, so as not to mix with the downstream clean water areas.

Dirty water infrastructures amount to approximately 15 km^2, which is a conservative estimate. The percentage loss in MAR for all of the quaternary catchments ranges from 2 % to 3 % as shown in Table 8-9. This loss in MAR is considered negligible.

[1] Regulations on Use of Water for Mining and Related Activities aimed at the Protection of Water Resources; GN R704 in Government Gazette 20119 of 4 June 1999

Table 8-9: Loss in MAR due to proposed infrastructure

Quaternary Catchment	Total Area (km^2)	Infrastructure Area (Km^2)	MAR (Mm^3)	% Loss in MAR	Loss in MAR (Mm^3)
C22J	669	15	11.81	2	0.26
C23D	510	15	9.12	3	0.27
C23E	850	15	13.41	2	0.24
C23J	890	15	18.49	2	0.31

8.5.4 Surface Water Quantity

Surface water drainage within the project area occurs in three directions, with the main rivers being the Leeuspruit, Klein Wes Rietspruit, the Wonderfontein Spruit and the Loop Spruit. The following sections will quantify the flow from these rivers, whilst also looking at the impacts of the project on their respective flow.

8.5.4.1 Wonderfontein Spruit

The Wonderfontein Spruit is divided into the Upper and the Lower Wonderfontein Spruit and is responsible for draining surface water runoff emanating from the Driefontein and Kloof mining areas. The source of the Upper Wonderfontein Spruit is the Tudor Dam, located north, of the Donaldson Dam, the Leopards Vlei Dam and the Lancaster Dam.

The Upper Wonderfontein Spruit ends at the outflow of the Donaldson Dam, where a 1 m pipeline signifies the beginning of the Lower Wonderfontein Spruit. The Lower Wonderfontein Spruit is made up of the 1 m pipeline, which extends approximately 30 km down the natural drainage path of the Wonderfontein Spruit.

Approximately 33 ML per day (33 000 $m^3.day^{-1}$) is being discharged into the Wonderfontein Spruit from the K10 Shaft, together with additional discharges of 20 ML per day (20 000 $m^3.day^{-1}$) from Cooke 1 Shaft. Therefore, total flows discharged to the Wonderfontein Spruit *via* the 1 m pipeline currently amounts to 53 ML per day (53 000 $m^3.day^{-1}$).

Over and above the 53 ML per day entering the 1 m pipeline on the Upper Wonderfontein Spruit, there are discharges into the Wonderfontein Spruit of approximately 15 to 20 ML per day from the Flip Human WWTW, and on the Lower Wonderfontein Spruit, approximately 10 ML per day is discharged directly into the 1 m pipeline from the Hannes van Niekerk WWTW.

During re-mining, approximately 20 ML per day (20 000 $m^3.day^{-1}$) from K10 Shaft will be used within the RTSF process, together with 12 ML per day from Cooke 1 Shaft, resulting in total discharges to the 1 m pipeline decreasing from 53 ML per day (53 000 $m^3.day^{-1}$) as a result of mine discharges to 21 ML per day (21 000 $m^3.day^{-1}$) as a result of an estimated 32 ML per day (32 000 $m^3.day^{-1}$) being used for the reclamation process.

Current flows are measured to be 72 123 $m^3.day^{-1}$ on average. Decrease in flows in the Wonderfontein Spruit is expected to range between 37 to 55 percent at the outlet of the 1 m pipeline.

Currently at the downstream end of the 1 m pipeline, approximately 130 ML per day is being measured as a result of Driefontein discharges of 50 ML per day as well as 80 ML per day from the outlet of the 1 m pipeline. During re-mining, 32 ML per day will be removed from the pipeline, resulting in flows decreasing to 98 ML per day, which should be still sufficient to accommodate the downstream users.

8.5.4.2 Leeuspruit

Flow in the Leeuspruit were estimated based on the catchment size contributing to the runoff on the downstream section of the stream, together with changes in runoff response due to seasonality (represented by runoff factors). The catchment area reporting to the downstream section amounts to 107 km^2, with the runoff factors adopted to best represent conditions during the wet and dry seasons (0.05 for the wet season and 0.03 for the dry season).

Flows in the Leeuspruit can range from no flows during the dry season to a max of 24 593 $m^3.day^{-1}$ during the wet season. Flows in the Leeuspruit will increase from no flows been observed during the dry season to a constant 15 000 $m^3.day^{-1}$ flowing down the section of the Leeuspruit from the AWTF when re-mining commences. During the wet season peak flows can be as much as 39 593 $m^3.day^{-1}$.

8.5.4.3 Klein Wes Riet Spruit

Currently approximately 70 ML per day is abstracted as a result of underground dewatering activities at the Ezulwini Gemsbokfontein West dolomitic compartments. From the 70 Ml per day abstracted, 10 ML per day is discharged to the Leeuspruit (East), and the remaining 60 ML per day is discharged to the Klein Wes Riet Spruit. During re-mining of the historical TSFs, 20 ML per day will be used to mine the 1 Mt per month from Cooke 4 South TSF, resulting in a decrease of discharges from 60 ML per day to 40 ML per day. Therefore, there will be a decrease in current flows measured at the Klein Wes Riet Spruit.

Average flows in the Klein Wes Riet Spruit is estimated to be 69 612 $m^3.day^{-1}$. Decrease in flows in the Klein Wes Riet Spruit is expected to range between 27 to 33 percent downstream of the Peter Wright Dam. Water users include farming, cultivation, grazing. Estimated water use is estimated conservatively at 5000 $m^3.day^{-1}$. The water usage from the Klein Wes Riet Spruit in comparison to what is available is actually available during re-mining is still sufficient to cater for the demand.

8.5.4.4 Loop Spruit

Average flows in the Loop Spruit is estimated to be around 5 463 $m^3.day^{-1}$. There are currently no planned discharges or abstraction from the Loop Spruit.

8.5.4.5 Downstream Surface Water Monitoring at Riet Spruit

Currently flows reporting to the downstream section at the Riet Spruit after the confluence of the Leeuspruit experience an increase in flows. This is due to the 10 ML per day being discharged to the Leeuspruit East, and the 60 ML per day being discharged to the Klein Wes Riet Spruit. Flows from these watercourses will eventually report to the mentioned monitoring location on the Riet Spruit.

During re-mining 15 ML per day will be discharged from the AWTF together. However, there will be a decrease in flows into the Klein Wes Riet Spruit (20 ML per day). Therefore, in summary, flows will show a decrease on the Riet Spruit.

8.6 Land Use Conditions and Ownership

The project location was presented in Section 7.3, from which it is clear that the that the infrastructure associated with the WRTRP is widespread in a north-south as well as an east-west direction. The purpose of this section is to provide an overview of the land use and human behavioural conditions as observed in the region. In addition to providing context to the potential affected environment, this information also provides the basis to define receptors as part of a Source-Pathway-Receptor analysis approach.

Within the assessment framework presented in Figure 5-1, the SPR analysis approach is used as basis to define and justify public exposure conditions. The conditions presented here is largely based on the *primary study area* description provided in the socio-economic scoping report (Digby Wells Environmental, 2015f). The primary study area is the area likely to experience social impacts related to the physical intrusion of project infrastructure and project-related activities up to a few hundred metres from the edges of a project's footprint.

8.6.1 Land Use Conditions and Ownership

Figure 8-19 presents an overview of the land ownership along the linear infrastructure associated with the WRTRP. Major land uses within the primary study area include agriculture (arable), grazing, urban and peri-urban residential areas, mining and business uses, as well as natural veld land use conditions. Agriculture is the dominant land use condition, followed by mining and residential land uses, with the latter accounting for less than 10% of the total land area. Agricultural activities within the study area comprise commercial maize and soya farming, as well as livestock grazing. The largest section of commercial farming land coinciding with the primary study is situated within the RTSF footprint, followed by the area within the CPP site. Livestock, mostly cattle, is also grazed throughout the primary study area.

The broader project area includes a large number of historical and existing mining activities. However, the CPP and RTSF sites comprise 'greenfield' projects. Pipeline routes will, as far as possible, follow existing road- and power line servitudes.

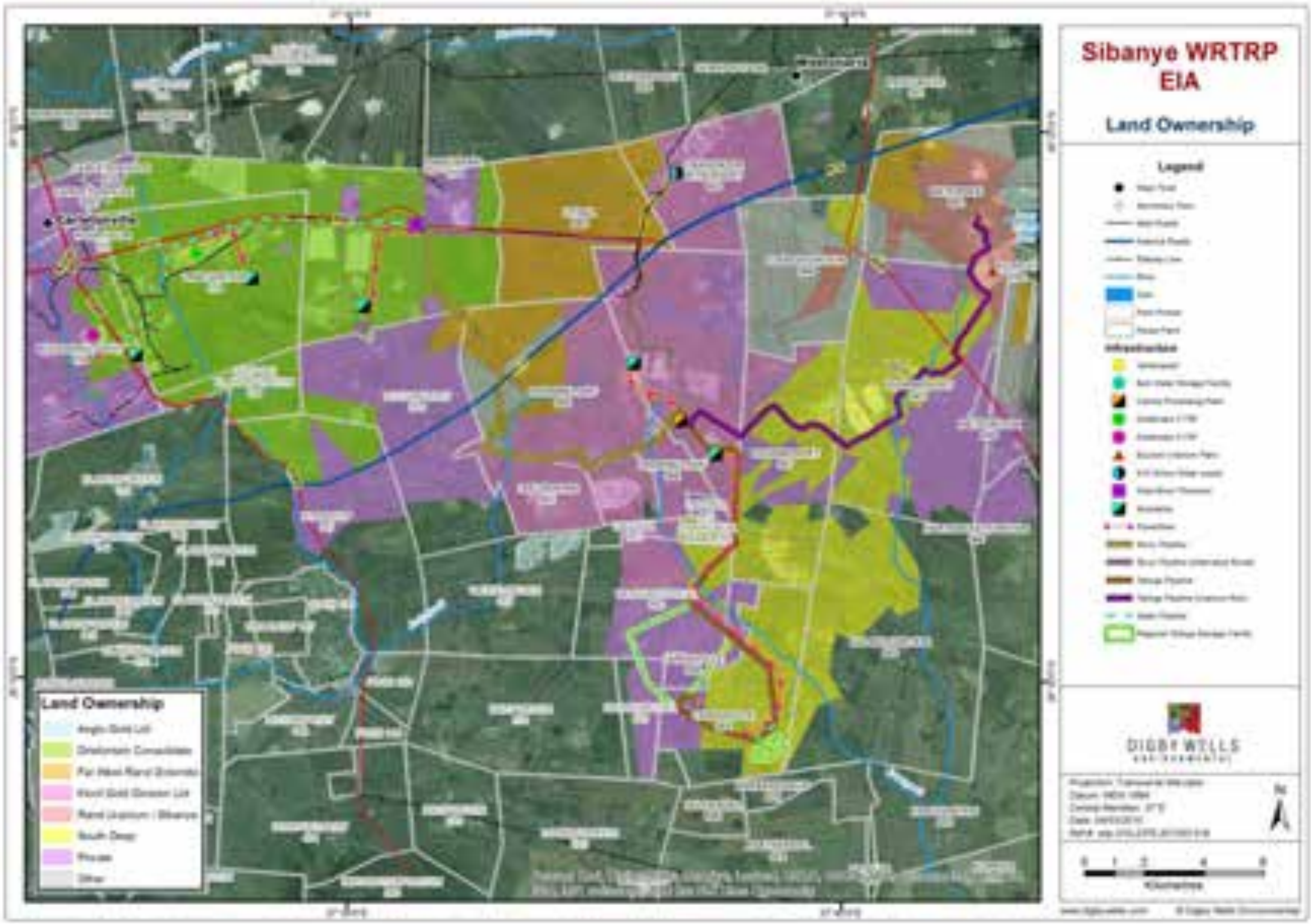

Figure 8-19: Land ownership along the linear infrastructure associated with the WRTRP in the primary study area (Digby Wells Environmental, 2015f).

The municipalities' human settlements are relatively scattered due to the mining activities taking place. Towns and larger settlements located within the broader project area include Randfontein, Mohlakeng, Carletonville, Westonaria, Venterspost, Rietvallei, Bekkersdal, Toekomsrus, Modderfontein, Hillshaven, Glenharvie, Simunye, Fochville, and mining towns such as Libanon and Waterpan. Residential land use comprises both formal and informal uses. Formal structures are either occupied by tenants who rent properties from mostly mining companies or landowning families farming on privately owned property. Informal structures are usually occupied by farm workers and their families, and/or illegal occupants.

Infrastructure and facilities/structures in the study area include formal and informal dwellings, buildings used for business purposes (e.g. commercial farming infrastructure, mine infrastructure, roadside shops), privately owned infrastructure (e.g. access roads, boreholes and dams), public infrastructure (e.g. roads) and several abandoned residential structures.

A large number of tarred and gravel roads traverse the study area. These roads are used on a daily basis to commute between farms and mines, as well as to and from urban centres such as Carletonville and Fochville.

The retreatment of the historical TSFs will provide an opportunity for alternative land uses to be implemented in the affected areas. However, a decision in this regard will only be made the achievement of the remediation and rehabilitation parameters.

8.6.2 Socio-economic characteristics and livelihoods

The scoping assessment highlights that several households within the primary study area are likely to rely on the land within the proposed footprint for their livelihood, especially those involved in commercial agriculture. Apart from agriculture related livelihoods, it is anticipated that a large number of those who are employed within the study area are working in surrounding mines or towns such as Carletonville or Fochville.

The socio-economic characteristics of households within the primary study area are likely to be similar to that of the secondary study area, which suggests that households residing in temporary or informal structures within the relatively rural primary study area are likely to be impoverished and vulnerable, with limited access to public services. Households residing in formal structures within the area are likely to have a higher socio-economic status and access to services. Education and skills among the population in the study area are expected to be lower than the regional average.

9 Radiological Baseline and Project Related Conditions

As part of the regulatory process administrated by the NNR, SGL is required to characterise the radiological baseline for the areas potentially affected by the WRTRP. This process, which normally includes area gamma and dose rate surveys of the affected areas, full spectrum radioanalysis of soil, water and sediment, as well as measurements of airborne radon concentrations, were sub-contracted to the South African Nuclear Energy Corporation

(Necsa). Note that some of the pipelines routes were surveyed as part of the Gold Fields WWP and Rand Uranium CUP approval process.

Section 9.1 provides a summary of the results presented in NECSA (2015). The second part of this section (Section 9.2) presents a summary of the radioanalysis results available for the tailings resources associated with the WRTRP. Note that the airborne radon concentrations, as well as the full spectrum analysis results for the soil, water, and sediment are not yet available for inclusion in this report.

9.1 Summary of the Radiological Site Characterisation

Necsa performed a baseline radiological survey of the CPP, RTSF and associated RWD areas. Included in the survey were the proposed pipelines routes for the transfer of water, tailings and concentrate between surface infrastructure located in the different Mining Right areas. The purpose of the survey was to characterise the baseline radiological conditions of the potentially affected areas and to determine the levels of naturally occurring radionuclides.

Results of the radiological survey are documented in a report entitled *Interim Report on the Radiological Baseline Study Performed for the West Rand Tailings Retreatment Project: Sibanye Gold* (NECSA, 2015). The following sections present a summary of the gamma survey and dose rate measurement results, as well as a description of the physical samples collected in the area.

9.1.1 Gamma Spectrometric Survey

Gamma spectrometric measurements were collected during July and August of 2015 at all accessible areas within the proposed infrastructure footprint areas and the immediate surrounding environment. The measurements were collected by means of a calibrated Sodium Iodide Spectrometer, which provides readings for K-40, Ra-226 and Ra-228 nuclide concentrations in the surface soil.

The measurements of Ra-226 and Ra-228 concentrations collected in areas where no mine activities had previously taken place, can be used to estimate concentrations of other nuclides in the uranium and thorium decay series, by assuming secular equilibrium.

Measurements at the proposed infrastructure footprint areas (e.g., CPP; RTSF and thickeners) were taken on a 100 m x 100 m grid, while measurements along the length of the proposed pipeline routes were collected at intervals of 500 m.

The survey report lists all 1 749 individual measurements of K-40, Ra-226 and Ra-228 concentrations collected during the survey. Graphical representations of the results are also provided in the form of coloured dots overlain on a map of the area. Figure 9-1 shows an example of the R-226 concentration measured along the pipeline routes as well as over the proposed footprint areas of the WBT and RTSF. Each dot represents the location of a measurement and is coloured according to the concentrations measured at that location. Table 9-1 is a summary of the results collected during the survey.

Table 9-1: Summary of gamma spectrometric measurements (NECSA, 2015).

Parameter Description	Activity Concentrations ($Bq.g^{-1}$)		
Nuclide	**K-40**	**Ra-226**	**Ra-228**
Average	0.52	0.06	0.05
Median	0.42	0.05	0.04
Minimum	0.19	0.02	0.02
Maximum	2.70	1.21	0.12
Std Deviation	0.28	0.07	0.01

Interpretation of the gamma survey results is based on comparing the measured activity concentrations to the regulatory exclusion level for radioactive nuclides in the soil, which is defined as the maximum activity concentration of 0.5 $Bq.g^{-1}$ per individual nuclide of the uranium and thorium decay in the soil and 10 $Bq.g^{-1}$ for K-40 (NNR, 1999).

Figure 9-1: Example of gamma spectrometric results reported for the proposed WBT and CPP footprint areas and the associated pipeline routes (NECSA, 2015).

The results are further compared to published global average and median natural background activity concentration ranges. NECSA (2015) specify the following concentration ranges:

- Ra-226 average activity concentration range: 0.050 $Bq.g^{-1}$ to 0.070 $Bq.g^{-1}$
- Ra-226 median activity concentrations range: 0.017 $Bq.g^{-1}$ to 0.060 $Bq.g^{-1}$
- Ra-228 average activity concentration range: 0.010 $Bq.g^{-1}$ to 0.090 $Bq.g^{-1}$
- Ra-228 median activity concentration range: 0.011 $Bq.g^{-1}$ to 0.064 $Bq.g^{-1}$
- K-40 median activity concentration range: 0.14 $Bq.g^{-1}$ to 0.85 $Bq.g^{-1}$

The NECSA (2015) report concluded that the average and median results for all the measurement locations fall within the concentration ranges listed above. Comparison of the individual measurements with the regulatory exclusion level indicated that only 8 measurements exceed the 0.5 $Bq.g^{-1}$ level for nuclides of the U-238 decay chain. These measurements were collected along the proposed pipe route between the Driefontein No.3 and Driefontein No.5 TSFs (see Figure 9-2).

Figure 9-2: Locations of gamma survey results exceeding exclusion levels (NECSA, 2015).

9.1.2 Gamma Dose Rate Measurements

Gamma dose-rate measurements were collected using a calibrated dose-rate monitor equipped with a Geiger Muller counter. Measurements were taken on contact with the soil, as well as at a 1 meter distance from the ground surface. NECSA (2015) report that the gamma dose-rate measurements were collected at the same positions used for the collection of gamma spectrometric measurements. Table 9-2 presents a summary of the gamma dose rates measured over the project area. The individual dose-rate readings were compared with an average natural background range of 0.06 – 0.20 µSv.h^{-1}. Only four locations associated with the Driefontein No. 5 TSF exceed this range (NECSA, 2015). The dose measurement results thus serve to confirm the findings of the gamma spectrometric measurements.

9.1.3 Soil, water and sediment samples

NECSA collected a number of surface soil samples at fixed locations along the proposed pipeline routes and infrastructure footprint areas. Samples of water and sediment were also collected from surface water streams and rivers as well as from boreholes in the project area.

Table 9-2: Summary of gamma dose rate measurements (NECSA, 2015).

Parameter Description	Contact dose rate (µSv.h^{-1})	One meter dose rate (µSv.h^{-1})
Average	0.21	0.20
Median	0.21	0.19
Minimum	0.06	0.06
Maximum	0.64	0.78
Std Deviation	0.07	0.06

The samples were submitted to the RadioAnalysis laboratory at NECSA for radio-chemical analysis. The samples were submitted on the 1st of September 2015, and results are expected to become available early 2016. Figure 9-3, Figure 9-4 and Figure 9-5 show the respective locations at which the surface soil, water and sediment samples were collected.

9.2 Radioanalysis Results of Tailings Resources

During the initial phases of the project, the sources of the tailings that will be processed at the CPP and eventually transferred to the RTSF include the Driefontein No 3 and No 5 TSFs located in the Driefontein Mining Right area, as well as the Cooke and Cooke 4 South TSFs located in the Cooke Mining Right area. However, several different resources will be utilised over the life of the Ultimate Project (see Section 7.4). A pre-feasibility report on the metallurgy of the WRTRP presents data indicating the grade and recovery of uranium from the available resources. A summary of this information is presented in Table 9-4, for ease of reference.

Table 9-3 lists the nuclide specific activity concentrations for TSFs associated with the Driefontein Mining Rights area. The values were obtained from a worker safety assessment report for the Driefontein Mine performed in 2010 (Gold Fields, 2010).

Table 9-5 summarises the full spectrum radiological analysis of a reprocessed Cooke TSF sample (analysis performed by the SGS Laboratories in France). A distinction is made between the different particle sizes of the sample. Table 9-5 shows a significant decrease in activity concentrations for larger particles sizes (more than 10 micron). The less than 10 micron particles are significant in terms of inhalation, while the more than 10 micron particles are significant in terms of deposition.

Figure 9-3: Locations of surface soil samples collected for the WRTRP baseline radiological survey (NECSA, 2015).

Figure 9-4: Locations of surface water and groundwater samples collected for the WRTRP baseline radiological survey (NECSA, 2015).

Figure 9-5: Locations of surface water and groundwater samples collected for the WRTRP baseline radiological survey (NECSA, 2015).

Table 9-3: Summary of nuclide specific activity concentrations in tailings materials associated with the Driefontein Mine (Gold Fields, 2010).

Nuclide	All	Driefontein 4	Driefontein 3	Driefontein 2	Driefontein 1
	Bq.kg^{-1}				
U-238	522.0	108.0	166.0	912.0	930.0
U-234	60.6	60.6	166.0	912.0	930.0
Th-230	60.6	60.6	166.0	912.0	930.0
Ra-226	512.0	111.0	127.0	946.0	871.0
Pb-210	710.0	181.0	136.0	1200.0	1030.0
Po-210	710.0	181.0	136.0	1200.0	1030.0
U-235	24.0	5.0	7.7	42.0	42.8
Th-232	25.4	15.4	15.7	30.8	39.8
Ra-228	36.3	9.5	0.0	39.3	57.2
Th-228	24.6	17.2	19.6	25.3	37.9
Ra-224	24.6	17.2	19.6	25.3	37.9

Table 9-4: Summary of uranium grades and projected recoveries in tailings from the Sibanye resources (MDM, 2013).

Resource	Existing TSFs			
	Tonnes	Grade	Content	Recovery
	[Mt]	[g.t^{-1}]	[Mlb]	[%]
Dam 38	15.7	67	2.32	36%
Dam 39	77.3	45	7.67	28%
Dam 40/41	74.5	49	8.04	28%
Venterspost North	54.5	52	6.25	28%
Venterspost South	12.7	43	1.2	28%
Cooke TSF	86.3	180	34.25	80%
Driefontein 1	35.8	65	5.13	36%
Driefontein 2	37.4	59	4.87	28%
Driefontein 3	49.8	74	8.12	36%
Driefontein 4	60.3	18	2.39	0%
Driefontein 5	27.9	54	3.33	25%
Libanon	73.3	42	6.79	28%
Kloof 1	28	26	1.6	31%
Kloof 2	44.5	31	3.04	46%
Leeudoorn	21.9	35	1.69	28%
South Shaft	23.7	79	4.12	27%
Twin Shaft	29.7	70	4.59	36%

TSF 4	55.5	78	9.54	36%
Total Surface Resources	808.8	69	114.9	
New Arisings				
Resource	**Tonnes**	**Grade**	**Content**	**Recovery**
	[kt. mo^{-1}]	**[g.t^{-1}]**	**[klb.mo^{-1}]**	**[%]**
Cooke Current Arisings	90	190	37.7	51%
Driefontein Current Arisings	240	47	24.87	39%
Kloof Current Arisings	205	29	13.11	0%
South Deep Current Arisings	330	75	54.56	32%
Total Current Arisings	865	73	130.24	

Table 9-7 presents a summary of radioanalysis results for various TSFs associated with the Cooke and Ezulwini operations collected in recent years (van Blerk, 2015a), although not all these TSFs are necessarily associated with the WRTRP.

The results presented in Table 9-8 are of two samples that were collected from the top surface of the Ezulwini North TSF, where tailings are actively deposited.

The results summarised in Table 9-9 are of two tailings samples collected on the same day in February 2012 from the side slope of the Ezulwini North TSF. The first sample (RA-12635) is of a composite sample of tailings collected from a deeper layer of tailings material from 1 to 2 m below the surface. The second sample (RA-12636) is a composite tailings sample collected from the surface layer (0 to 1 m) of tailings on the side slope of the TSF.

Table 9-5: Full spectrum radiological analysis of a reprocessed Cook TSF tailings sample (analysis performed by the SGS Laboratories in France) (van Blerk, 2012).

Particle Size	< 10 micron	10 to 100 micron	> 100 micron
	Bq.kg^{-1}		
U-235	86.8	40.9	25
Ac-228	202	43.5	28.2
Pb-212	559	49.9	33.2
Th-228	129	30	19.7
Bi-214	2744	586	326
Pb-214	2755	567	323
Ra-226	3330	-	-
U-238	859	219	132

Assuming the following assumption, the weighted average for each radionuclide listed in Table 9-6 can be derived Table 9-5 (van Blerk, 2012):

- U-234 and Th-230 was assumed to be in equilibrium with U-238;
- Ra-226 was assumed to be equal to Bi-214;
- Pb-210 was assumed to be in equilibrium with Ra-226;
- Ra-228 was assumed to be equal to Ac-228;
- Th-232 was assumed to be equal to Ra-228; and

- Secular equilibrium is assumed between the parent and daughter products.

Table 9-6: The weighted average activity concentration of the Cooke TSF sample, assuming secular equilibrium between parent and daughter products (van Blerk, 2012).

Radionuclide	Mass per Particle Size (g)			Total Mass (g)
	5	193	202	400
	Particle Size			
	< 10 micron	10 to 100 micron	> 100 micron	Weighted Average
	Bq.kg^{-1}			
Th-232	202.0	43.5	28.2	37.8
Ra-228	202.0	43.5	28.2	37.8
U-238	859.0	219.0	132.0	183.1
U-234	859.0	219.0	132.0	183.1
Th-230	859.0	219.0	132.0	183.1
Ra-226	3330.0	586.0	326.0	489.0
Pb-210	3769.0	509.0	308.0	448.2
Po-210	3769.0	509.0	308.0	448.2
U-235	86.8	40.9	25.0	33.4
Pa-231	86.8	40.9	25.0	33.4
Ac-227	86.8	40.9	25.0	33.4

Table 9-7: Nuclide specific activity concentrations measured in tailings samples from the Cooke and Ezulwini TSFs.

TSF	Sample	U-238	U-234	Ra-226	Po-210	Pb-210	U-235	Th-232	Ra-228	Th-228	Necsa Ref. No.
		Bq.kg^{-1}									
Millsite TSF	38A	50.1	50.5	97.9	74.9	-	2.3	8.6	8.6	8.6	Ra-09259
	38B	870	877	418	349	-	40.0	22.5	22.5	22.5	
	39	1270	1280	590	366	-	58.3	35.2	35.2	36	
	40	72.6	73.2	104	62.2	-	3.3	11.3	11.3	11.3	
	41	38.6	39.0	111	94.8	-	1.8	9.2	9.2	9.2	
Cooke TSF	Cooke Plant	107	108	2020	1150	-	4.9	29.3	41	29	
Cooke 4 South TSF	Old No. 4	580	585	1250	793	-	26.7	34.4	35	73.2	
Ezulwini North TSF	New No. 4	449	453	1210	646	-	20.7	23.7	43	38	
Dump 20	Dump 20 Sand	55.7	56.1	161	118	-	2.6	10.8	10.8	10.8	
	Residue	235	-	240	-	282	10.8	23.7	26.4	18.5	RA-08169
	Thickener U/F	236	-	217	-	300	10.9	23.4	32.0	22.9	
	Dump 20 Spiral Sand	96.9	97.7	139	-	239	4.5	14	10	14	RA-14827
	Dump 20 Slimes A+B	974	-	707	-	883	449	43.4	43.2	36	RA-14814
Lindum TSF	Lindum Slimes A+B	696	-	918	-	1160	32.1	47.9	45	35	

Table 9-8: Radionuclide content of recently deposited tailings.

Radionuclide	2010 Sample (RA-11028)		2011 Sample (RA-12425)	
	Value	Uncertainty	Value	Uncertainty
	Bq.kg^{-1}			
U-238	2 060	30	453	5
U-234	2 080	30	453	4
Ra-226	2 260	50	1 090	20
Pb-210	2 560	80	1 610	120
U-235	95	1.3	20.9	0.2
Th-232	89	3.2	42.6	0.8
Ra-228	103	18	46.5	9.1
Th-228	106	13	50.2	7.7
K-40	392	64	120	3
Gross α	17 100	400	12 100	1 500
Gross β	7 490	70	3 330	140

Table 9-9: Radionuclide content of tailings on the side slope of the TSF.

Radionuclide	1 to 2m Sample (RA-12635)		0 to 1 m Sample (RA-12636)	
	Value	Uncertainty	Value	Uncertainty
	Bq.kg^{-1}			
U-238	242	10	395	16
U-234	244	10	398	16
Ra-226	939	22	6 330	110
Pb-210	38.8	8.4	6 620	160
U-235	11.1	0.5	18.2	0.7
Th-232	23.4	0.9	102	4
Ra-228	21	8.6	186	34
Th-228	27.6	5.7	217	23
K-40	209	33	767	115
Gross α	9 180	1 340	33 600	2 400
Gross β	2 780	140	15 500	300

Table 9-10 to Table 9-13 present radioanalysis results for various TSF within the Kloof Mining Right area. It includes Kloof 1, Kloof No. 7 (Leeudoorn), Libanon No. 10 and Venterspost No. 2. Some of the analysis results dates back to 2002, while more recent results are for 2014 and 2015.

9.3 Activity Concentration for the RTSF

Most of the TSFs listed above will be reprocessed as part of the WRTRP, which will result in a reduction in the uranium concentrations, and a possible enrichment of other radionuclides.

Table 9-10: Nuclide specific activity concentrations in samples of gold plant tailings collected at operational plants at the Kloof Operations (Necsa Report No. RA-4036 dated 14 February 2002).

Nuclide	Kloof No.1		Leeudoorn No.7		Libanon No.10		Ventersport No.2	
	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
	Bq.kg^{-1}							
U-238	358	4	524	5	87.9	2	84.7	1.9
Ra-226	443	31	534	36	1230	60	86.9	18.3
Pb-210	244	36	560	46	1090	80	<82	-
U-235	16.5	0.2	24.1	0.3	4.05	0.09	3.9	0.09
Th-232	20.2	1.5	25.9	1.4	52.4	2.5	13.6	0.9
Ra-228	<130	-	<120	-	<210	-	<100	-
Th-228	29.6	9.7	24.6	9.4	91.5	34.1	<55	-
K-40	293	116	355	143	1040	210	<410	-
Gross α (Bq.g^{-1})	3.62	0.22	4.09	0.24	9.16	0.34	1.01	0.14
Gross β (Bq.g^{-1})	4.54	0.07	6.26	0.08	10.4	0.1	1.57	0.04

To estimate activity concentrations of what might be disposed of at the RTSF, the average activity concentrations of the Driefontein, Cooke and Kloof TSF were used to derive an overall activity concentration. With no sample available yet for the prospective assessment, this approach was assumed to be reasonable. Table 9-11 presents a summary of the resulting activity concentrations. Note that secular equilibrium was assumed between some of the daughter and parent radionuclides.

Table 9-11: The average activity concentrations observed in the Driefontein, Kloof and Cooke TSFs, as well as the average within the TSFs of the three Mining Right areas.

Nuclide	Driefontein	Cooke	Kloof	Average
	Bq.kg^{-1}			
U-238	529.0	396.4	220.6	382.0
U-234	517.2	399.5	221.5	379.4
Th-230	517.2	399.5	221.5	379.4
Ra-226	513.8	635.0	318.7	489.1
Pb-210	636.8	629.9	301.9	522.8
Po-210	636.8	417.3	301.9	452.0
U-235	24.4	21.3	10.1	18.6
Th-232	25.4	23.5	20.7	23.2
Ra-228	26.5	25.1	22.7	24.8
Th-228	25.0	28.5	28.1	27.2

Table 9-12: **Nuclide specific activity concentrations in samples of tailings collected from the Kloof No.7 (Leeudoorn) TSF over a period of 15 months.**

Necsa Report Number	RA-15408		RA-16279		RA-16619		RS2015-0046		*RA-15803*	
Sample Date	January 2014		July 2014		October 2014		January 2015		April 2014	
Nuclide	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
	Bq.kg^{-1}									
U-238	241	8	249	9	163	8	90.6	2.7	209	4
U-234	243	8	251	9	-	-	91.4	2.8	210	4
Ra-226	215	8	274	10	154	7	319	19	197	8
Pb-210	247	30	316	33	190	22	509	36	0.281	0.034
U-235	11.1	0.4	11 .5	0.4	7.5	0.37	4.17	0.13	9.61	0.20
Th-232	21.7	0.7	22.6	0.8	19.8	0.9	11.6	0.6	28.5	1.0
Ra-228	12	4.3	31.1	7.7	12	6.3	62.8	16.5	23.4	6.8
Th-228	23.6	8.2	28.3	10.6	17	2.3	< 100		26.8	9.9
K-40	153	23	245	32	165	28	120	75	149	26
Gross α	2960	190	1610	280	1640	260	2610	740	2300	290
Gross β	1100	20	1390	40	1010	30	1030	90	1030	40

Table 9-13: Nuclide specific activity concentrations in samples of tailings collected from the Kloof No.1 TSF over a period of 15 months.

NECSA Report Number	RA-15408		RA-16279		RA-16619		RS2015-0046		*RA-15803*	
Sample Date	January 2014		July 2014		October 2014		January 2015		April 2014	
Nuclide	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
	Bq.kg^{-1}									
U-238	82.5	2.9	163	6	94.1	4.7	536	14	205	4
U-234	83.2	2.9	164	6	-	-	540	14	207	4
Ra-226	60.0	4.1	96.3	5.8	158	7	496	25	198	8
Pb-210	70.2	20.6	155	26	189	24	569	40	0.234	0.028
U-235	3.80	0.13	7.50	0.26	4.33	0.22	24.7	0.6	9.44	0.20
Th-232	10.2	0.7	9.53	0.49	12.1	0.9	26.0	0.9	16.1	0.7
Ra-228	13.8	4.0	11	5.0	12	5.6	< 97		2.0	4.7
Th-228	12	2.5	13	2.1	14	2.2	< 140		9.9	4.8
K-40	147	20	96.9	23.3	146	27	< 460		146	25
Gross α	1650	150	670	220	2660	300	3970	910	2870	310
Gross β	488	16	671	29	881	34	1900		937	35

9.4 Radioanalysis result of water released to the Leeuspruit

Current planning indicates that the AWTF would discharge treated water into the Leeuspruit. Although the technology that has been identified as the preferred method for treatment will produce water of potable quality (in accordance to SANS 241: 2014), it is reasonable to expect that the water may contain trace levels of radionuclides. To determine the potential impact release of the treated water will have on the water quality of the Leeuspruit, it is necessary to estimate the radionuclide content of the treated water.

The chemical quality of the water entering the RWD, was predicted using a saturation chemistry model. The model predicts the composition of the RWD inflows, which will remain substantially unchanged at saturation (during the dry season), but will be diluted during the wet season. Concentrations of several elements and ions, as well as water quality parameters, are predicted and reported as a range (minimum and maximum) and average values in units of $mg.L^{-1}$. Table 9-14 presents s summary of the predicted total concentration of uranium in the return water.

Table 9-14: Predicted concentrations of uranium in the RTSF return water.

Parameter	Estimated Total Uranium Concentration ($mg.L^{-1}$)
Minimum	0.150
Maximum	0.169
Average	0.161

To determine whether these values are reasonable concentrations, given the origin of the return water, it can be compared to monitoring measurements of return water at the Ezulwini Operations. At Ezulwini, the wastewater generated in the mining activities underground is combined with fissure water that enters the underground workings, and is pumped to a surface dam. Results of quarterly monitoring samples collected over a period of two consecutive years was consulted. Table 9-15 presents the average concentrations of radionuclides measured in the Ezulwini Monitoring samples. To compare the values, the average uranium concentration listed in Table 9-14, was converted to nuclide specific uranium activity concentrations, by using the natural abundance of the three uranium isotopes (U-238, U-234 and U-235) and the specific activity of each. The results are listed in the last column of Table 9-15.

The comparison shows that the modelled concentration of uranium is similar to the measured concentrations from Ezulwini. Given this result, and the fact that no information is available for other radionuclides in the RTSF return water, the average measured concentrations of the Ezulwini return water will be used as representative of what can be expected in the water treated at the AWTF.

The treatment objective of the AWTF is water that is fit for human consumption, for which the SANS 241: 2014 standard dictates that the uranium concentration must be below 15 $\mu g.L^{-1}$. At this concentration, the activity concentrations of the three uranium isotopes should be approximately 185 $mBq.L^{-1}$ (U-238), 198 $mBq.L^{-1}$ (U-234) and 8.6 $mBq.L^{-1}$ (U-235). This is approximately 10 times lower than the estimated return water uranium concentration listed in Table 9-15, and approximately 15 times lower than the activity concentrations of uranium measured at Ezulwini. Using the measured activity concentrations of the Ezulwini return water, a reduction factor of 15 is therefore assumed. Based on this assumption the activity concentrations of radionuclides in the treated water leaving the AWTF were calculated, as listed in Table 9-16.

Table 9-15: Comparison of average measured nuclide specific activity concentrations estimated uranium isotope activity concentrations in RTSF return water.

Radionuclide	Measured Activity Concentrations Ezulwini Return Water	Estimated Uranium Isotope Activity Concentrations WRTRP Return Water
	$mBq.L^{-1}$	
Th-232	5.2	-
Ra-228	5.2	-
U-238	2695.4	1988
U-234	2554.0	2122
Th-230	51.0	-
Ra-226	180.9	-
Pb-210	171.3	-
Po-210	8.4	-
U-235	125.7	92.8
Pa-231	125.7	-
Ac-227	125.7	-

Table 9-16: Estimated nuclide specific activity concentrations in RTSF return water.

Radionuclide	Measured Activity Concentrations Ezulwini Return Water	Estimated Activity Concentrations Treated Water from the AWTF
	$mBq.L^{-1}$	
Th-232	5.2	0.36
Ra-228	5.2	0.36
U-238	2695.4	185
U-234	2554.0	175
Th-230	51.0	3.5
Ra-226	180.9	12.4
Pb-210	171.3	11.8
Po-210	8.4	0.58
U-235	125.7	8.6
Pa-231	125.7	8.6

9.5 Radioactivity Released from the CPP

To estimate the radionuclide content of particulates emitted from process stacks at the CPP, it is necessary to evaluate the processes and materials from which the particulates will originate. According to the process description for the CPP there are two processes that will include high temperature components. These processes are the acid plant roaster and the gold plant smelter. In general, uranium processing may include a calcine furnace for thermal treatment of the final ADU product. However, current descriptions of the CPP process does not include calcining and it is assumed that this will be performed at another facility that does not form part of the broader WRTRP.

Of the two thermal processes noted, only the acid plant roaster is likely to receive materials that contain radionuclides. The gold concentrate sent to the gold plant smelter for refining has been hydrometallurgical and electrochemical processes and is assumed to contain very little radionuclides if any. Emissions from the smelter are therefore accepted to be free of radionuclides and are therefore not considered relevant in terms of radiological impact.

The acid plant toaster will process pyrite, separated from the recovered tailings in the flotation cells. Pyrite is known to contain radionuclides, implying that particulate emissions from the roasting process may also include radionuclides.

There is no information currently available on the radionuclide concentration the pyrite contained in the tailings that will be recovered through the WRTRP. Pyrite recovery and processing is also not very common among the mining operations included in the WRTRP, so no information in this regard could be obtained from processes located in the West Rand region.

In the absence of a sample from the WRTRP process, a 2009 pyrite sample from the Vaal Reefs Gold Mine near Klerksdorp in North West will be used. The results are summarised in Table 9-17.

Table 9-17: Results from Necsa analysis (RJ-2009-1078) for the Vaal Reefs pyrite sample.

Nuclide	Activity (Bq.kg^{-1})
U-238	4610
U-234	4640
Ra-226	8710
Po-210	11900
U-235	212
Th-232	274
Ra-228	251
Th-228	206
Gross Alpha	70800
Gross Beta	25700

10 Development of Public Exposure Conditions

Within the conceptual assessment framework presented in Figure 5-1, the concept of defining discrete public exposure conditions is designed as a logical process for screening the myriad of possible circumstances that may lead to radiation exposure. This process simplifies the selection of appropriate assessment parameters, within which a defensible assessment of current and future public radiation safety can be presented.

Different approaches can be used to derive public exposure conditions. For the purpose of this assessment, a Source-Pathway-Receptor analysis approach was judged to be appropriate.

The SPR analysis consists of three interrelated steps. The first step is to identify the *sources* of radiation exposure. The sources are characterised in terms of its unique characteristics that will determine how contaminants may be released and distributed in the environment. There is also a temporal component to the characteristics of the sources (e.g. whether in the operational period or post-operational period). The identification of contaminant release mechanisms for the various sources therefore include a reference to the period of concern.

Secondly, all relevant pathways and routes of exposure that relate to the identified sources and contaminant release mechanisms have to be identified and evaluated for their relevancy. In this context, *pathways* refer to the means by which radionuclides may be dispersed or transferred within or between compartments of the environmental system, to a point where humans interact with the compartment (i.e. environmental pathways such as atmospheric or groundwater dispersion). An *exposure route* refers to the route of entry into the human body to pose a radiation risk, such as through ingestion, inhalation, or external exposure.

Finally, receptors are defined and characterised. In this context, *receptors* refer to humans (i.e., members of the public) that may potentially be subject to radiation exposure (i.e. a radiation dose) from the identified sources and through the exposure pathways and routes of concern.

10.1 Sources of radiation exposure

The detailed description of the WRTRP presented in Section 7 serves as the basis for the identification and description of sources of radiation exposure.

> Note that *all* potential mechanisms of radiological contaminant release have to be identified as part of the source identification (even if it has a low likelihood of occurrence), to ensure a transparent analysis of all potential sources.

10.1.1 Release mechanisms

To pose a radiological risk to members of the public and the environment, naturally occurring radionuclides first have to be *released* from the sources of radiation exposure into the environment. Release mechanisms can be generalised into the following natural and artificially induced conditions:

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

Controlled and uncontrolled releases may be induced naturally or through human intervention. Examples of uncontrolled releases are accidents and incidents that may include, pipeline bursts or releases from storage dams overflowing its capacity.

A distinction can be made between primary and secondary sources of radiation exposure. *Primary sources* are defined as physical features or entities where naturally occurring radionuclides are released, or stored as NORM with the potential to be released to the environment. Examples of primary sources include:

- Tailings Storage Facilities (TSFs), Waste Rock Dumps (WRDs) or any other stockpile facility used to store waste or other residue material on surface, from which naturally occurring radionuclides may be dispersed in solid (dust), liquid (seepage), or gaseous (radon gas) form;
- Mineral processing activities, where radioactive gasses and dusts may be released from the commination (crushing and milling) and beneficiation of ore containing radionuclides (e.g., stacks);
- Water management facilities (e.g. evaporation or return water dams), used to manage excess water generated through the mining and processing operations, and where water may be released;
- Materials handling activities (e.g. the transfer of material from one point or facility to the next), during which radioactive dusts may be released; or
- Mine ventilation facilities, used to manage airflow in underground workings, where gasses and dusts may be released.

Radioactivity released from primary sources through natural or human induced conditions may accumulate in physical compartments of the environment system (e.g. groundwater, surface water bodies, surface soils, sediments, etc.), potentially resulting in what can be termed *secondary sources* of radiation exposure. The following serve as examples of secondary radiation sources:

- Continuous deposition and accumulation of radionuclides associated with airborne dust on surface soils,

- Continuous deposition of radionuclides associated with airborne dust onto a surface water body, resulting in the accumulation of contaminants in sediments and water;
- Spillage of raw materials that contain radionuclides on surface soils, resulting in the development of a secondary source on the soil surface; or
- Uncontrolled (e.g. spillage) release of contaminated mine residue (e.g. tailings material) or water on surface soils or water resources.

Members of the public may be subject to radiation exposure from both primary and secondary sources. The significance of primary or secondary sources will vary on a site-specific basis.

10.1.2 Primary sources of radiation exposure

The purpose of this section is to identify the primary sources of radiation exposure associated with the WRTRP. These sources are diverse in nature, associated with all four Mining Right areas, and as a result widespread.

Note that some of the facilities and activities discussed below will be excluded as possible sources of radiation exposure to members of the public, but will still be managed as part of the broader EMP and RMP (see Section 17).

10.1.2.1 Pipelines and associated pump stations

Section 7.4.3 identified six different types of pipelines stretching over a distance of 120 km to transfer water, tailings material (slurry) and products (uranium concentrate) and as a result connect different surface infrastructure components associated with the broader WRTRP. Generally, the pipelines are accessible to members of the public in the open veld. However, under normal operating conditions (i.e., while the pipelines are intact with no releases to the environment), these pipelines do not serve as a source of radiation exposure to members of the public. Even if a member of the public spent considerable time near a pipeline, the person may only be subject to low levels of gamma radiation, which will largely be shielded off by the pipeline itself.

The transfer of water, tailings materials (slurry) and products (uranium concentrate) is an integral part of the process, for which pump stations are required. Under normal operating conditions and similar to the pipelines, pump stations do not serve as a source of radiation exposure to members of the public.

Pipelines and pump stations is consequently not considered as source of radiation exposure to members of the public in the assessment. Conditions outside the normal operation of pipelines and pump stations (i.e. accidents and incidents) are discussed as part of secondary sources in Section 10.1.3.

10.1.2.2 Thickeners

Two thickeners are planned as part of the Initial Implementation of the WRTRP. These thickeners will be used to thicken reclaimed tailings from the TSFs before it is pumped to the

CPP for processing. It will be located within access controlled areas of the existing infrastructure at the Driefontein Operation and Cooke Operation. This means that members of the public will not have uncontrolled access to the thickeners, and therefore these facilities does not serve as a source of direct gamma radiation to members of the public.

The design and operation of a thickener is such that releases to the environment are not possible. The thickeners are 65 m diameter sealed tanks that do not allow leakage to the environment, while any overflow is diverted away from the tank and back into the system. Solid, gas and water mediated release of radionuclides to the environment is thus not likely and therefore the thickeners will not be considered as sources of radiation exposure to members of the public in the assessment.

10.1.2.3 Abstraction of water and bulk water storage facilities

The hydraulic reclamation of the historical TSFs is a water driven process that requires large quantities of water to operate. The preference will be to use currently impacted mine water for this purpose. Bulk Water Storage Facilities (BWSF) will be used to store excess water abstracted from exiting shafts such as K10 shaft at the Kloof Operations, Cooke 1 and Cooke 2 Shafts at the Cooke Operations, and Cooke 4 shaft at the Ezulwini Operations. However, the abstraction of water from these shafts in itself does not serve as a source of radiation exposure to members of the public. It may even result in the reduction of water released to the environment, such as K10 water released to the Wonderfontein Spruit, or water abstracted from the Gemsbokfontein West compartment released to the Leeuspruit and the Klein Wes Riet Spruit (Digby Wells Environmental, 2015i).

Once abstracted, water will be transferred to the BWSF. As with the thickeners, the BWSF will be located within existing security controlled areas, which means that members of the public will not have uncontrolled access to the complexes under normal operating conditions.

Furthermore, the design and operation of a BWSF is such that releases to the environment are not possible (i.e., application of a zero releases policy). The BWSF is therefore not considered as source of radiation exposure to members of the public in the assessment.

10.1.2.4 Central Processing Plant

It follows from Section 7.4.5 that the CPP located within existing infrastructure of the Kloof Operations, will eventually comprises a number of modules to extract gold, uranium and sulphur from the reclaimed tailings material. Since the CPP will be located within a secured area, members of the public will not have uncontrolled access to the facility and therefore does not serve as a source of direct gamma radiation to members of the public

Dust particles (PM_{10}) containing naturally occurring radionuclides may be released from the stacks associated with the different modules to the atmosphere (solid-mediated release of radionuclides). However, the quantity of radionuclides released to the atmosphere in this way is expected to be minimal, but will nevertheless be considered in the assessment.

The facility will be designed and operated in such a manner that all water run-off that may occur will be accumulated and contained in pollution control dams to comply with a zero release policy for the facility. Water mediated releases of radionuclides to the environment through the aquatic pathways are therefore not expected.

10.1.2.5 Regional Tailings Storage Facility

The RTSF will be used for the disposal of tailings material generated at the CPP and the AWTF. A TSF generally serves as a source of radiation exposure to members of the public, through solid-, gas- and water-mediated release of contaminants, in the following manner:

- Windblown dust emitted from a TSF (PM_{10} and TSP) contains naturally occurring radionuclides, which are dispersed into the atmosphere, resulting in a quantifiable concentration of airborne radioactivity (solid mediated release);
- The radionuclide content of the tailings material results in the emission of radon gas that is dispersed into the atmosphere, resulting in a quantifiable concentration of airborne radioactivity (gas mediated release); and
- Infiltration and subsequent percolation of water through the TSF induces leaching of water soluble radionuclides. Water seeping from the TSF may contain leached radionuclides, which are then transported to the underlying geosphere from where it can contaminate groundwater and surface water resources (water mediated release).

Although not a contaminant in the usual sense, the inherent radiological properties of the tailings material continuously emit gamma radiation to the immediate surroundings.

10.1.2.6 Return Water Dam

The purpose of the RWD is to manage any excess water originating from the RTSF. It consists of a series of compartments, designed in such a manner that releases to the environment is unlikely. Not only will it comply with the requirements of regulation GN 704, the design will include a geocomposite liner consisting of a geomembrane underlain by a 300 mm thick layer of clayey material. A seepage collection system will also be provided to intercept and identify any leakage.

These design features means that under normal operating conditions, it is unlikely that the RWD will release water to the underlying aquifer. Furthermore, the RWD will be located within a secured area, thereby preventing uncontrolled public access to the facility. The RWD is therefore not considered as a source of radiation exposure to members of the public in this assessment, but will be retained as a possible source due to the nature of the facility.

Note that conditions outside the normal operation of the RWD (i.e. accidents and incidents) will be discussed as part of secondary sources in Section 10.1.3.

10.1.2.7 Advance Water Treatment Facility

The purpose of the AWTF is to treat the water stored in the RWD for release to the environment *via* the Leeuspruit. The facility itself will operate in a closed system, with only water treated to the appropriate quality to be released to the environment. The proposed treatment process is highly efficient and it is expected that the treated water can contain no more than trace quantities of residual naturally occurring radionuclides. However, the release of the treated water to the Leeuspruit will be treated as a potential source of radiation exposure to members of the public.

Residue material in the form of pellets is generated in the treatment process. Two different options are considered to manage the pellets, but both have as endpoint the disposal of the residue material as waste at the RTSF.

10.1.2.8 Reclamation of historical TSFs and collection sumps

All the historical TSFs are associated with current Mining Right areas and therefore have been evaluated from a radiological safety perspective as part of the NNR authorisation process, for current conditions. However, the planned reclamation activities are not expected to contribute additionally to the release of radionuclides from these facilities into the environment. Hydraulic reclamation of the TSF is a wet process, which eliminates any concerns of windblown dust generation. Although the hydraulic mining may introduce additional water into the system, most of the water is collected with the tailings slurry and is thus not available to transfer dissolved contaminants into the environment (i.e., surface water and groundwater).

Once the historical TSFs have been reclaimed and the footprints rehabilitated to a suitable end land use, the current solid, water and gas mediated radionuclide releases associated with the TSFs, will terminate. To acknowledge this positive impact of the WRTRP, a discussion that demonstrates the reduction of radionuclides present in the ambient atmosphere as a result of removing the historical TSFs will be presented. For this reason, the historical TSFs are retained as potential sources of radiation exposure in the assessment.

10.1.2.9 Extraction of uranium at Ezulwini and deposition at the Ezulwini North TSF

The initial Implementation of the WRTRP makes provision for 50 Mt per month of uranium concentrate produced at the CPP to be transferred to the Ezulwini Plant for further processing. The Ezulwini Plant currently processes less than 50 Mt per month, while they already received environmental authorisation to process up to 100 Mt of uranium concentrate per month. The additional 50 Mt per month from the WRTRP is thus within the current authorisation and is not expected to contribute to radiation exposure outside the current authorisation for the Plant.

Tailings from the processing of the WRTRP uranium concentrate will be deposited at the operational Ezulwini North TSF. As with the Ezulwini Plant, the Ezulwini North TSF is authorised for deposition of the full Plant capacity of 100 Mt per month, but currently receives less than half. Deposition of the additional 50 Mt per month is therefore within the environmental authorisation for the TSF, and is therefore not expected to contribute to radiation exposure outside the current authorisation for the TSF.

Both the Ezulwini Plant and the Ezulwini North TSF therefore remain operational and will continue to serve as sources of radiation exposure to members of the public.

10.1.3 Secondary sources of radiation exposure

It follows from Section 10.1.1 that secondary sources of radiation exposure may be associated with some of the primary sources of radiation exposure. These sources may manifest itself either due to gradual but continuous releases to the environment, or discrete events, which may result in water or solid mediated release of contaminants to the environment.

10.1.3.1 Continuous Releases

Continuous deposition of airborne dust (TSP) or irrigation with contaminated water will result in a steady increase in the radionuclide concentration of the soil, water and sediment, and over time create secondary sources of public radiation exposure.

10.1.3.2 Accidents and Incidents

The possibility exists that some part of the total system does not perform as designed under normal operating conditions. Of particular interest are uncontrolled releases to the environment from surface facilities. These include (amongst others) pipeline bursts that may result in solid or water mediated release of contaminants, overflow of storage dams (e.g., RWD or pollution control dams) that may result in water mediated release of contaminants, or the malfunctioning of a TSF that may result in solid mediated releases of contaminants.

Following such an event, and depending on the nature of the event, the tailings material or water released to the environment may serve as a secondary source of radiation exposure. However, such an event is normally a relatively short-term event, and may be managed in terms of the procedures included in the RMP (see Section 16).

10.1.4 Summary

Table 10-1 presents a summary of the different primary and secondary sources identified for the WRTRP, as well as the environmental pathways and associated release mechanisms of concern. Each source is supplemented with a description of the issues of importance.

10.2 Environmental Pathway Analysis

The most significant pathways through which members of the public may be exposed to radiation emitted from mining and mineral processing activities can be generalised as follows (IAEA, 2002):

- Atmospheric pathways that can expose members of the public to radionuclides through inhalation of airborne gases (e.g. radon and its progeny) and airborne radioactive particles;

- Atmospheric and terrestrial pathways that can expose members of the public to radionuclides through ingestion of contaminated soil and foodstuff and external radiation; and
- Aquatic pathways that can expose members of the public to radionuclides through the ingestion of contaminated water, foods produced using contaminated irrigation water, fish, and other aquatic biota, food derived from animals drinking contaminated water, and from external radiation.

The pathways listed above are generic and not necessarily equally applicable to all activities associated with the WRTRP. However, the potential sources and mechanisms of contaminant release listed in Table 10-1 suggest that the pathways of concern include the atmospheric, surface water, groundwater and external (gamma radiation) pathways.

Table 10-1: Summary of the different sources and their potential contribution for a radiological impact.

Source	Release mechanisms	Environmental pathways of concern	Description
Primary Sources			
Central processing plant (CPP)	Solid mediated release	Atmospheric pathway	The stacks may emit small volumes of dust particles (PM_{10}) to the atmosphere as a source for the atmospheric pathway.
Regional Tailings Storage Facility (RTSF)	Solid mediated release Water mediated release Gas mediated release Gamma radiation	Atmospheric pathway Groundwater pathway	The RTSF emits dust (PM_{10} and TSP) and radon gas particles to the atmosphere as a source for the atmospheric pathway. Leaching of contaminants to the underlying aquifer serve as a source for the groundwater pathway. The tailings material also continuously emits gamma radiation to the immediate surroundings.
Return water dam (RWD)	Water mediated release	Groundwater pathway	The RWD will be designed and constructed with a gecomposite liner that would make groundwater pollution very unlikely. The RWD is retained as a source due to its nature.
Advance Water Treatment Facility (AWTF)	Water mediated release	Surface water pathway	The AWTF itself is not a source, but is designed to release treated water to the Leeuspruit that may serve as a source.
Reclamation of historical TSFs	Solid mediated release Water mediated release Gas mediated release Gamma radiation	Atmospheric pathway Groundwater pathway	The TSFs currently serves as sources of radiation exposure and will continue to do so during reclamation. After reclamation, the TSFs are eliminated as potential sources of radiation exposure.
Ezulwini processing plant (uranium extraction)	Solid mediated release	Atmospheric pathway	The Ezulwini processing plant is operational, which means that dust particle is released to the environment. Processing of the uranium concentrate will continue to release particles, albeit still within the authorisation parameters. As a point source and in the presence of an area source such as the TSF, the emission of dust particles to the atmosphere is

Source	Release mechanisms	Environmental pathways of concern	Description
Primary Sources			
			expected to be insignificant.
Deposition of tailings at the Ezulwini North TSF	Solid mediated release Water mediated release Gamma radiation	Atmospheric pathway Groundwater pathway Surface Water Pathway	The Ezulwini North TSF is an operational and emits dust and radon gas particles to the atmosphere as a source for the atmospheric pathway. Leaching of contaminants to the underlying aquifer may serve as a source for the groundwater pathway. The tailings material also emits continuously gamma radiation to the immediate surroundings. Deposition of tailings from the processing of uranium concentrate will continue to serve as a source of radiation exposure, albeit within the authorisation parameters for deposition at the TSF.
Secondary Sources			
Pipelines	Solid mediated release Water mediated release	Surface environment Surface water pathway	Pipelines transferring tailings or water may serve as secondary sources following pipelines bursts and spillages on soil surface or at crossings with surface water bodies.
Atmospheric pathway sources	Solid mediated release	Surface environment Surface water pathway	Atmospheric pathway sources may deposit radionuclides on uncontaminated soil and on surface water bodies, resulting in a potential increase in the concentration of radionuclides in soil, water and sediment.
Water (surface water and groundwater) pathway sources	Water mediated release	Surface environment	The use of contaminated groundwater or surface water for irrigation may result in the increase in the concentration of radionuclides in soil.

10.2.1 Atmospheric pathway

Particulate matter is normally assessed as different particle size categories. Inhalable particulates are those with aerodynamic diameters less than 10 micron (PM_{10}), whilst the full particle size spectrum is normally referred to as Total Suspended Particulates (TSP). TSP is used with numeric dispersion modelling to represent dust deposition impacts, whereas the modelled airborne concentrations of PM_{10} are used to characterise health impacts related to dust inhalation. Since the airborne particulates generated and released from some of the facilities and activities associated with the WRTRP may include radionuclides, deposition and inhalation of the particulates may also lead to radiation exposure.

The presence of Ra-226 in WRTRP tailings further results in the exhalation of radon (Rn-222) gas into the atmosphere. The radon gas is distributed in the atmosphere, similar to particulates with very small aerodynamic diameters, and can therefore reach off-site locations. Inhalation of the radon gas can contribute to the radiation exposure of members of the public.

The WRTRP related sources identified in Section 10.1 that are of relevance to the atmospheric pathway are the historical TSFs (i.e., Driefontein No. 3, Driefontein No. 5, Cooke and Cooke 4 South TSFs), the RTSF, the CPP and to a lesser extent the Ezulwini processing plant. The impact of these facilities on the air quality were determined as part of the air quality impact assessment study (Digby Wells Environmental, 2015h).

Generally, airborne particulate and radon gas concentrations are highest close to the source and decrease with distance away from the sources depending on meteorological conditions and the physical terrain near the sources. Due to the physical differences in properties between particulate matter and gases, their dispersion and diffusion patterns may also differ.

One of the benefits of the WRTRP, is that the historical TSF will be removed as potential atmospheric pathway sources. This will have a positive impact as far as the air quality is concern, relative to current conditions. One would also expect a slight decrease in the potential dust load during the operational period, due to the (wet) nature of the reclamation process.

The Ezulwini processing plant has already received authorisation for the processing of up to 100 Mt per month. The additional 50 Mt per month of uranium concentrate will thus not have an influence in terms of the potential dust load for which the plant is already approved. In addition, the dust load from processing plant stacks tend to be relative insignificant, especially in the present of an area sources such as the Ezulwini North TSF. This notion is confirmed in Figure 10-1, which presents the simulated PM_{10} concentrations from the CPP (Digby Wells Environmental, 2015h). Note that no TSP and radon gas are released from the CPP stacks.

Figure 10-2 to Figure 10-4 present the simulated PM_{10}, TSP and airborne radon concentration concentrations for the RTSF, which clearly illustrates the notion that the concentrations are highest close to the source and decrease with distance away from the source. It also illustrates the difference in air dispersion and diffusion characteristics of the particulate matter and radon gas. A unit release rate (1 $Bq.m^{-2}.s^{-1}$) were used to generate the radon concentrations in Figure 10-4.

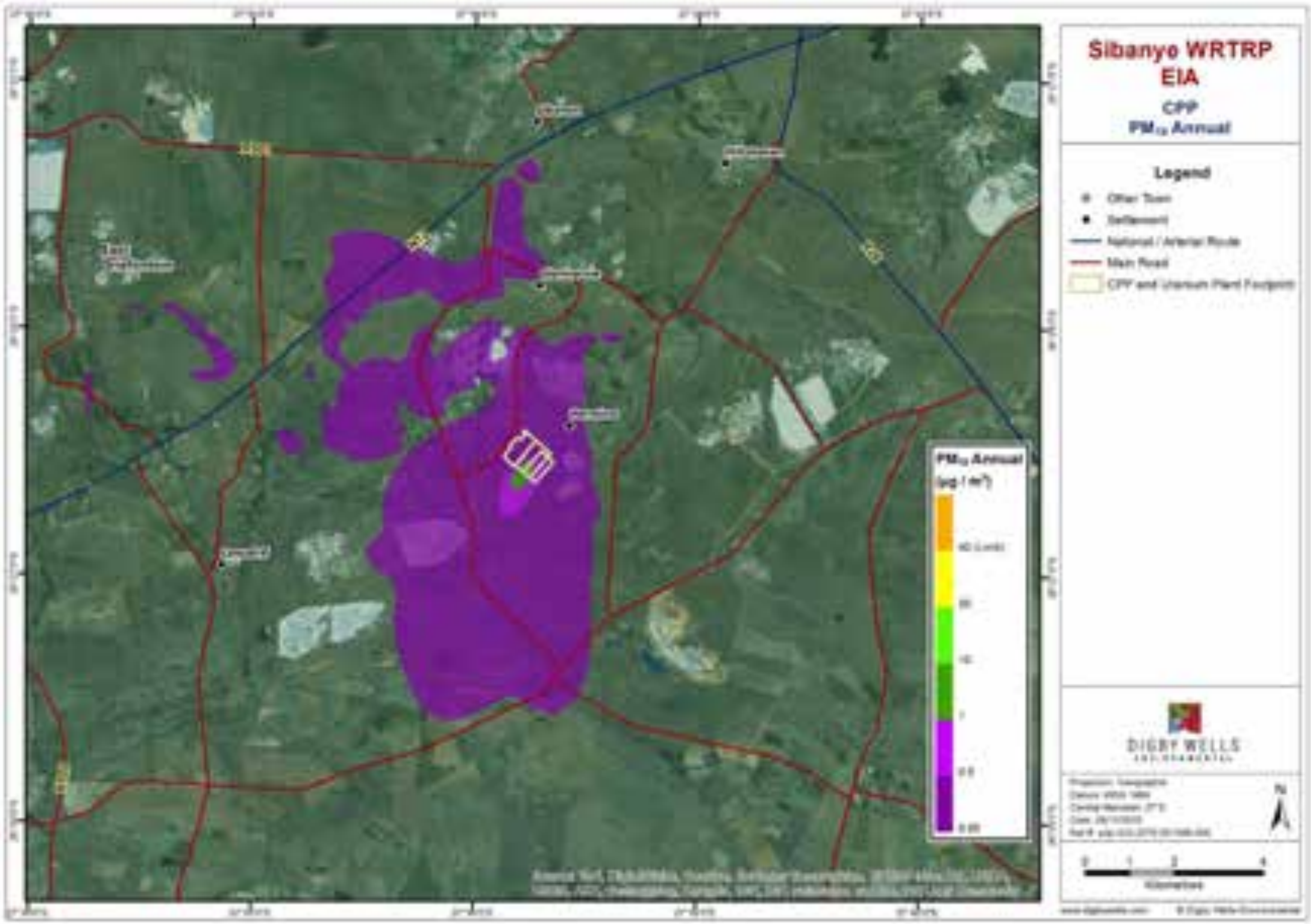

Figure 10-1: The simulated annual average PM_{10} concentration (100th Percentile, in units of $\mu g.m^{-3}$) for the CPP as part of the Kloof Operation (Digby Wells Environmental, 2015h).

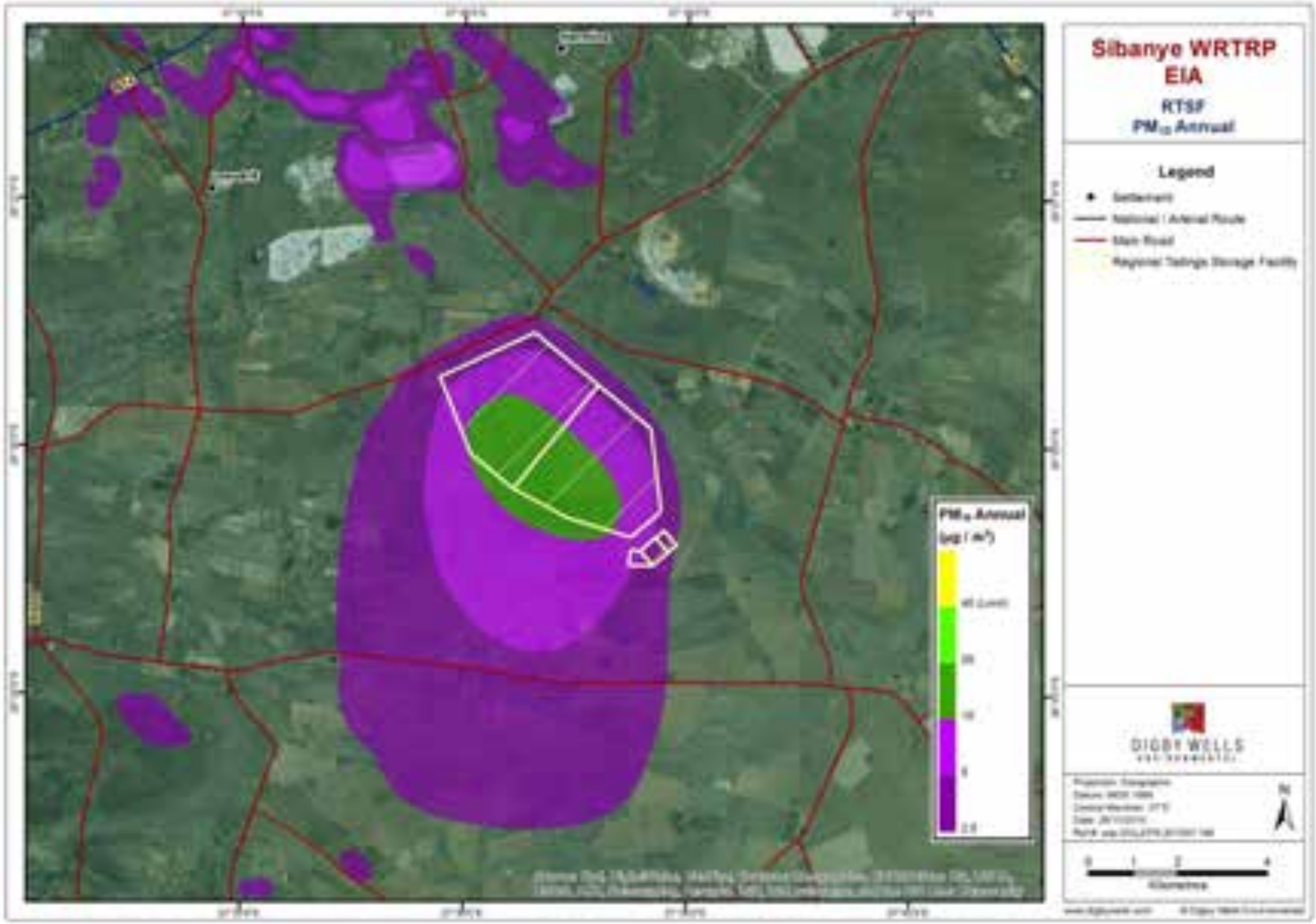

Figure 10-2: The simulated annual average PM_{10} concentration (100^{th} Percentile in units of $\mu g.m^{-3}$) for the RTSF as part of the Kloof Operation (Digby Wells Environmental, 2015h).

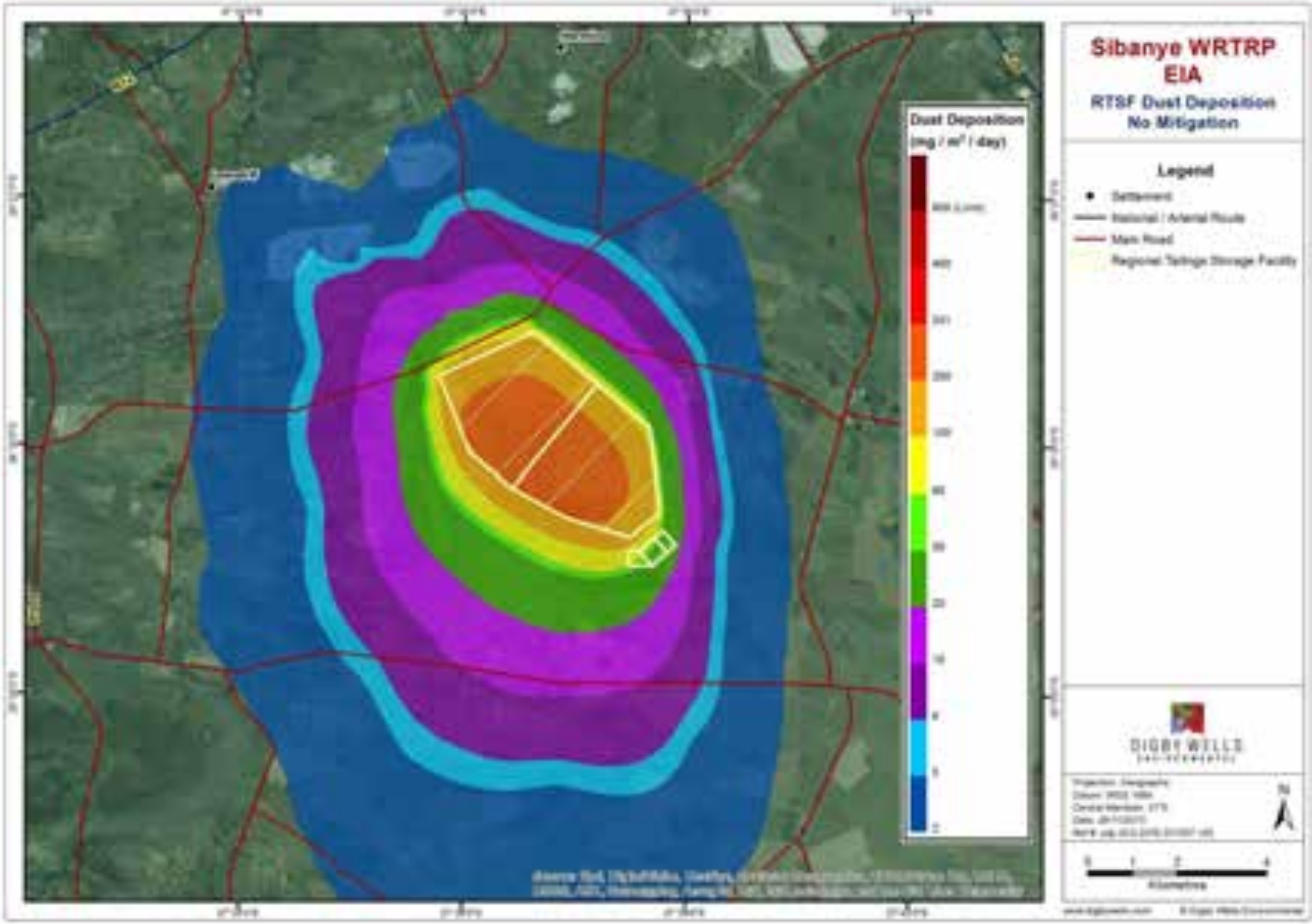

Figure 10-3: The simulated annual average TSP concentration (100th Percentile in units of mg.m^{-2}.day^{-1}) for the RTSF as part of the Kloof Operation (Digby Wells Environmental, 2015h).

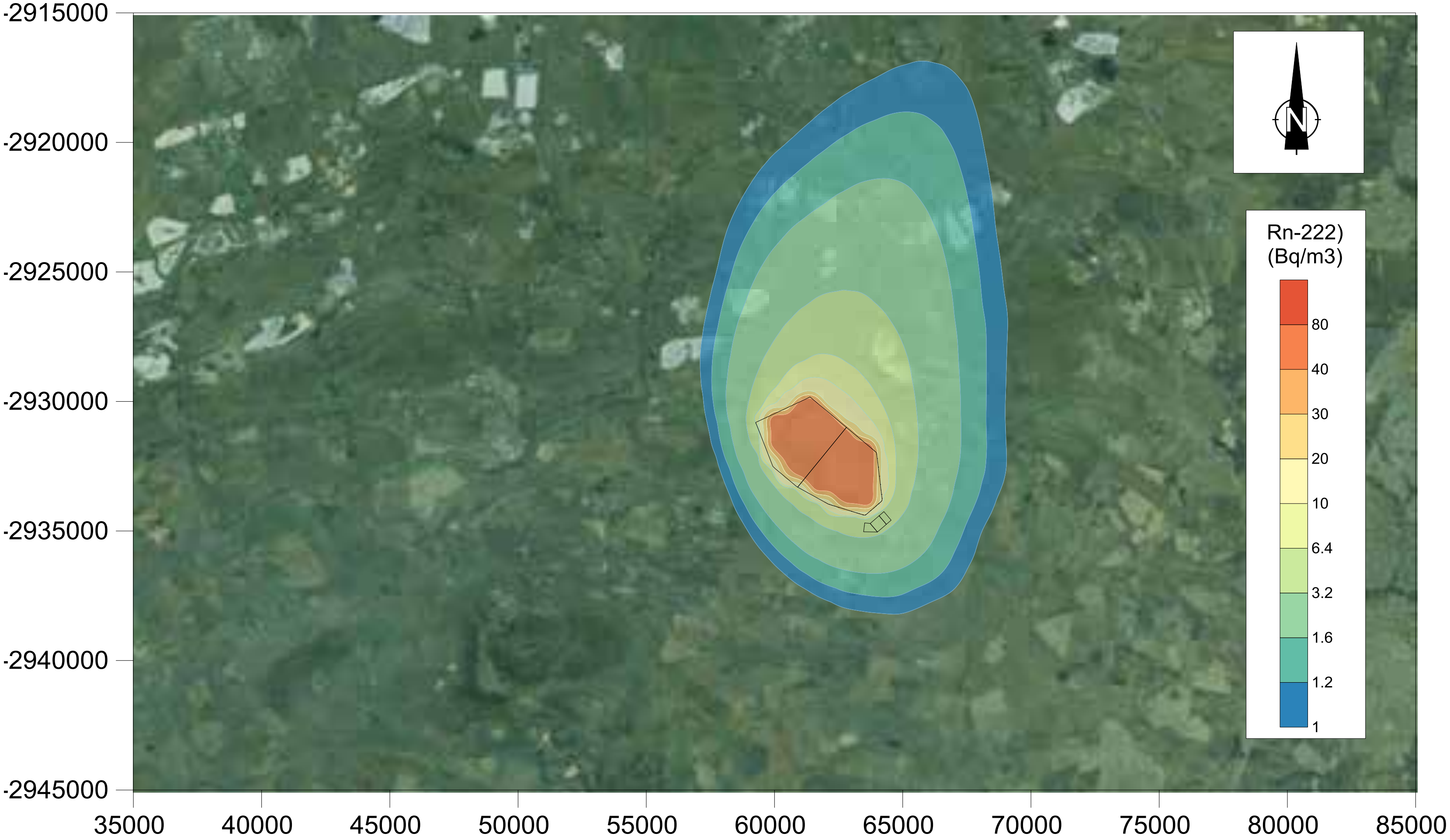

Figure 10-4: The simulated annual average airborne radon concentration (in units of Bq.m^{-3} using an exhalation rate of 1 Bq.m^{2}.s^{-1}) for the RTSF as part of the Kloof Operations (Parc Scientific, 2015).

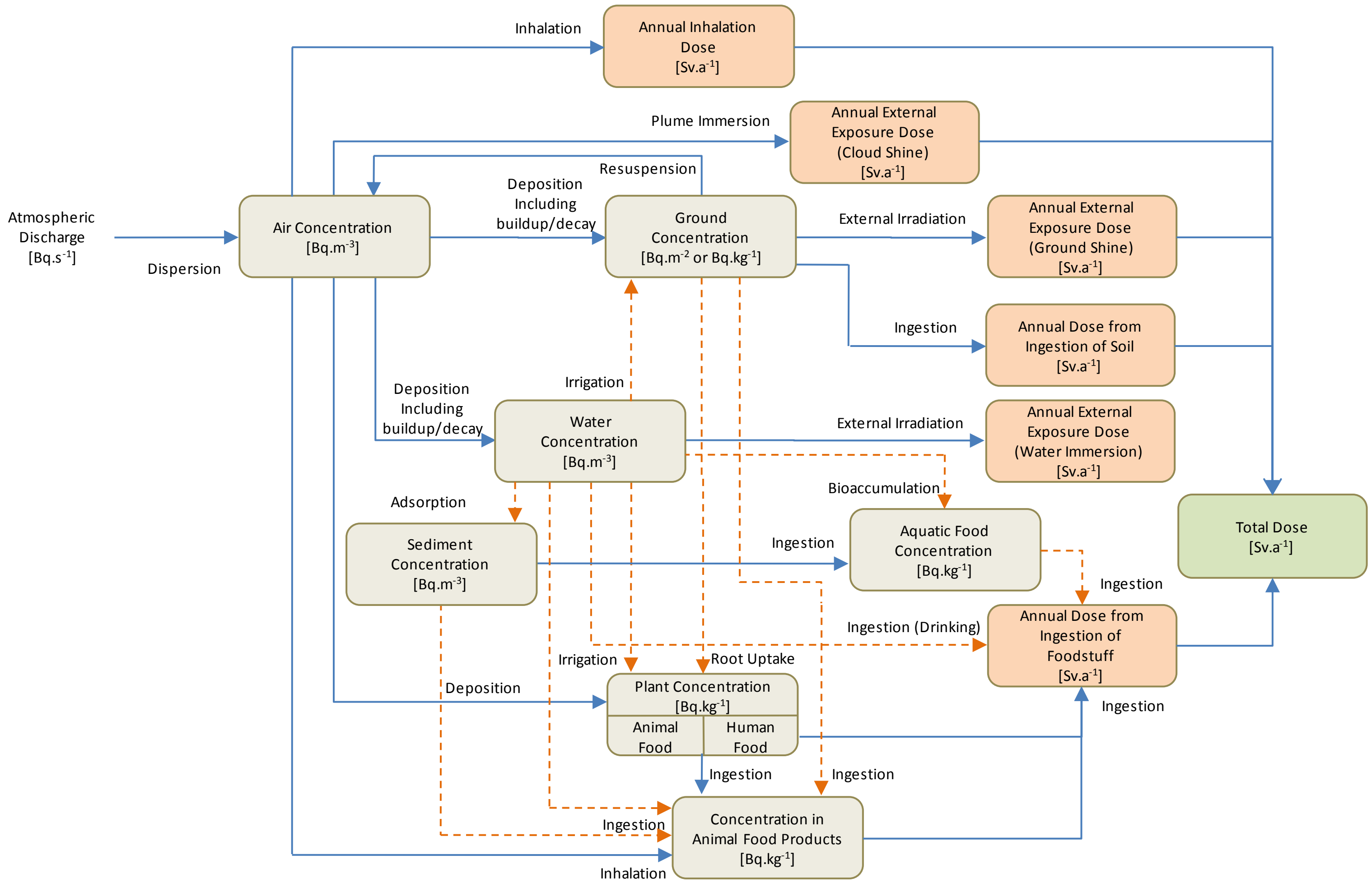

Figure 10-5: Features, processes and associated exposure modes that should be considered to calculate the contribution of the atmospheric pathway to a total dose.

The flow diagram in Figure 10-5 can be used to evaluate the contribution of the atmospheric pathway to a quantitative total effective dose. It follows from source description in Section 10.1 that airborne radioactivity can be attributed to the emissions of dust that contain long-lived alpha emitting radionuclides (LLα) and radon gas. Note that the airborne contaminant plume will contribute to the external gamma radiation dose (plume immersion) and inhalation of the airborne radioactivity contributes to the inhalation dose. As shown in Figure 10-5, airborne contaminants may be deposited onto the surface soils, resulting in a soil concentration. Depending on the prevailing atmospheric conditions, the contaminants deposited onto the soil may go into re-suspension, resulting in the further distribution of airborne contaminants. Exposure to the soil concentration also contributes to an external gamma radiation dose (ground shine). In a similar manner, airborne contaminants may be deposited onto the surface water bodies, contributing to the surface water pathway (see Section 10.2.3).

- The deposition of airborne contaminants can introduce secondary pathways that may contribute to a total effective dose. Of particular importance is the uptake of radioactive contaminants into the food chain. A number of processes influence the transfer of airborne contaminants to crops (including animal feed and human food) as part of the atmospheric pathway: Direct deposition and interception of contaminants onto crops;
- Deposition of airborne contaminants onto the soil surface, followed by root uptake of contaminates from the soil (or vice versa, biological decay of crops containing radionuclides may increase the soil concentration); and
- Transfer (through translocation) of the deposited contaminants to the plant structure.

Some of the contaminants will be lost during food preparation, while some will be washed of the plant (contributing to a soil concentration). Contaminants deposited on the soil can be transferred to plants through root uptake processes and so contribute to the annual effective dose of those individuals that consume the plants. Animal ingestion of contaminated crops or soil, or inhalation of airborne radioactivity may lead to the contamination of animal products such as dairy products, eggs, and meat.

Human ingestion of contaminated crops, soil, or animal products or the inhalation of airborne radioactivity (LLα and radon) will result in an internal dose. The total effective dose received through the atmospheric pathway is the sum of the individual doses received through the ingestion, inhalation, and external gamma exposure routes.

10.2.2 Groundwater pathway

The primary potential sources of radiation exposure (see Section 10.1) for the groundwater pathway associated with the WRTRP are the RTSF and the associated water management facilities such as the RWD and toe paddocks, and to a lesser extent historical TSFs. The impact of these facilities on the groundwater pathway were determined as part of the groundwater impact assessment study (Digby Wells Environmental, 2015g), some qualitative and others on a more qualitative basis. Of particular importance is the hydrogeological flow regime in the vicinity of these facilities.

The description of the hydrogeological conditions presented in Section 8.4 makes a distinction between the historical TSF located on dolomitic areas, and those located on non-dolomitic areas, as well as the RTSF site. The latter is described in detail in terms of the hydrogeological flow regime. The historical TSFs were not identified as significant sources of radiation exposure for the groundwater pathway, especially during the timescales of concern. In dolomitic areas any leaching will tends to be vertically downwards, while in non-dolomitic areas the migration will be limited to the weathered near-surface aquifer towards the lower lying areas such as the Wonderfontein Spruit, the Klip River in the east, and the Leeuspruit and associated streams towards the south. In both cases the lateral migration of radionuclides is expected to be limited over the timescales of concern.

For the RTSF, the description of the groundwater flow regime is presented in detail Digby Wells Environmental (2015g). Figure 10-6 shows the water levels and associated flow directions as derived from boreholes sampled during the hydrocensus, from which it is clear that the general drainage is in a south easterly direction towards the surface water bodies. The simulated groundwater flow regime presented in Figure 10-7 confirms this notion.

The flow diagram in Figure 10-8 can be used to calculate the contribution of the groundwater pathway to a quantitative total effective dose. Varying flow and geochemical process will cause contaminants to leach from the various groundwater pathway sources to the underlying aquifer, resulting in a groundwater concentration.

Through groundwater flow and radionuclide transport processes (e.g. advection, dispersion and diffusion), migration to various discharge points (e.g. surface water streams, rivers, dams, springs or boreholes) will occur. This will result in an increase in the groundwater concentration at these points. Groundwater movements may be very slow and geochemical reactions may retard the movement of radionuclides relative to the groundwater flow even further. Consequently, the radionuclides may take tens to thousands of years to migrate to groundwater discharge points such as boreholes (e.g. monitoring, drinking or irrigation borehole), fountains, and surface water bodies.

Depending on the radionuclide concentration of the groundwater as well as human habit and behavioural characteristics, various secondary pathways can contribute to a total effective dose, as illustrated in Figure 10-8. These pathways are very similar to those described for the atmospheric pathway, except that instead of deposition of airborne contaminants onto crops or soils, irrigation of water contributes to the concentrations of radionuclides in crops or soil.

10.2.3 Surface water pathway

Under normal operational conditions, the surface water pathway is an extension of the groundwater pathway and to a lesser extent the atmospheric pathway. However, the controlled or uncontrolled release of contaminated water or mine residue material may serve as a direct source of radiation exposure associated with the surface water pathway. Once discharged into the surface watercourse, radionuclides are subject to a series of physical and chemical processes that affect their transport from the point of discharge. These processes illustrated in Figure 10-9: include the following (IAEA, 2001):

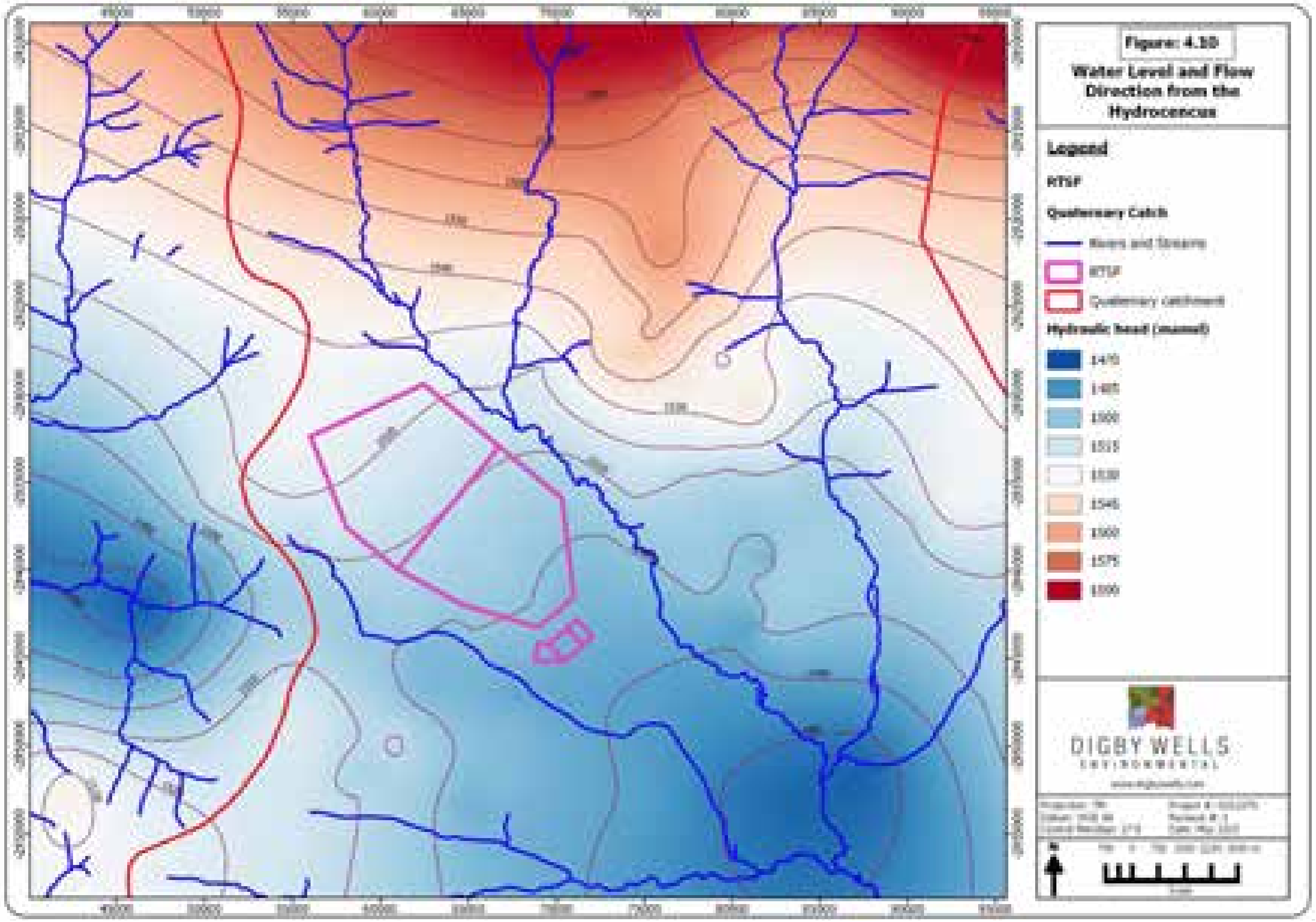

Figure 10-6: Map showing the water levels and associated flow directions as derived from boreholes sampled during the hydrocensus (Digby Wells Environmental, 2015g).

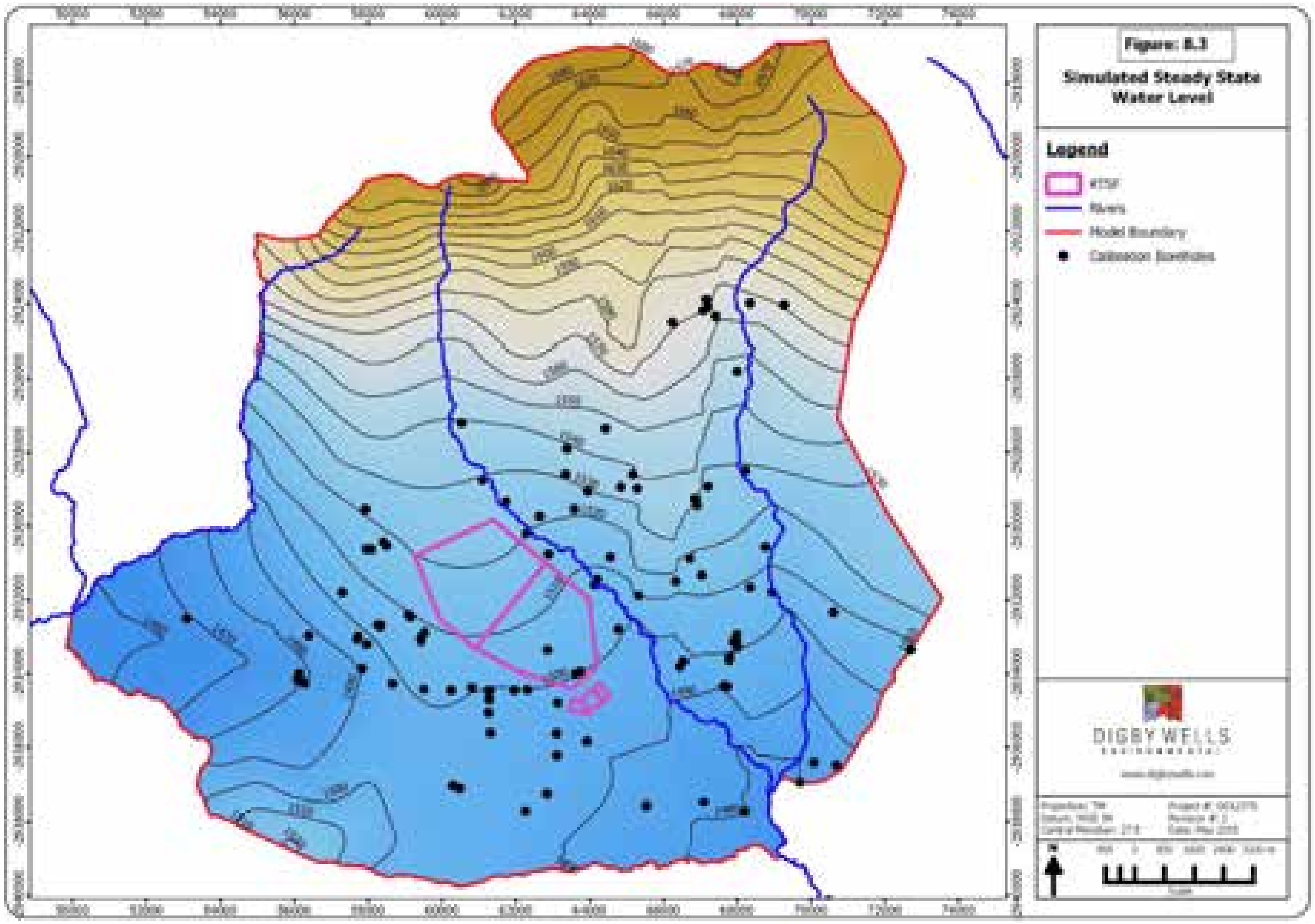

Figure 10-7: The simulated groundwater flow regime in the vicinity of the RTSF site (Digby Wells Environmental, 2015g).

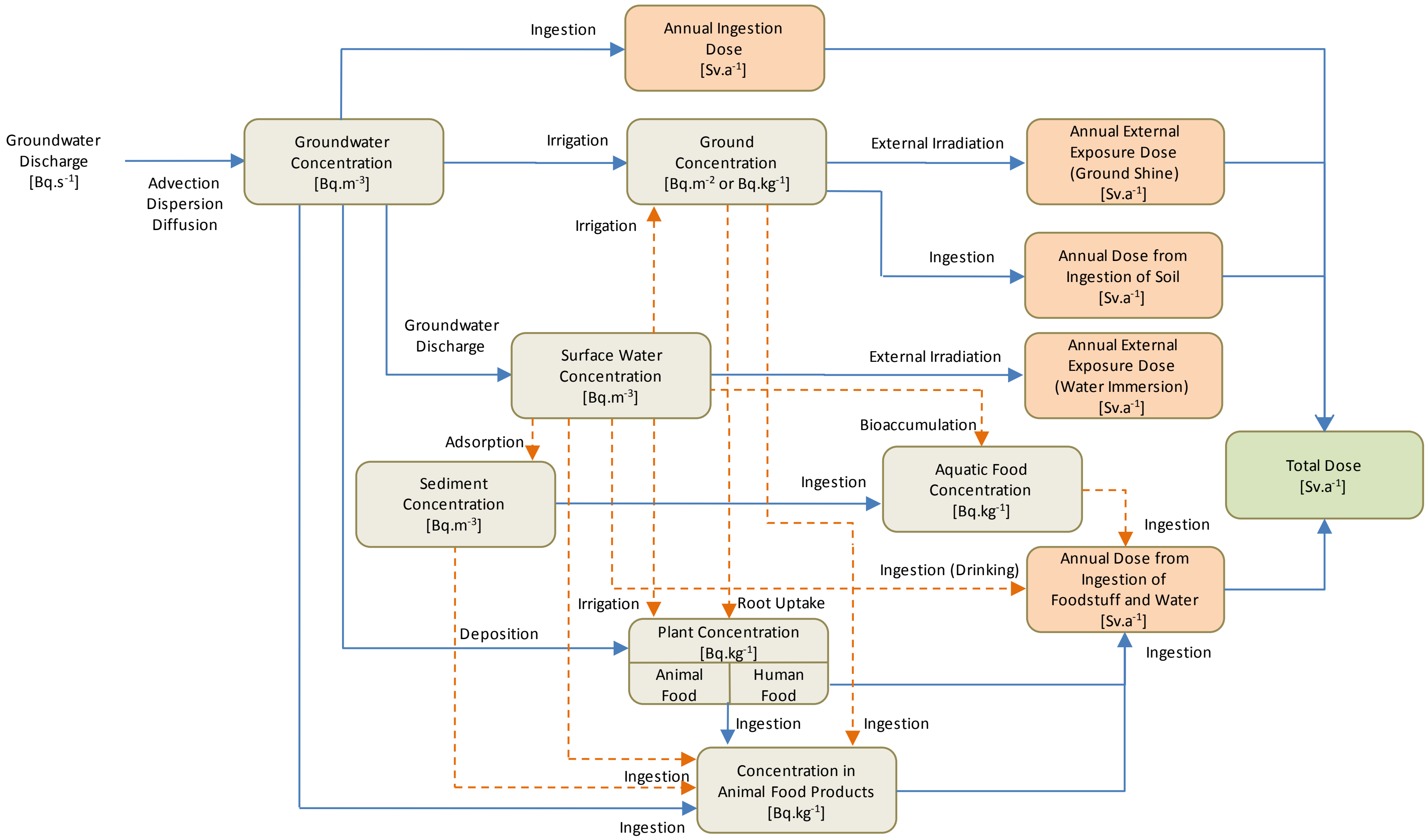

Figure 10-8: Features, processes and associated exposure modes that should be considered to calculate the contribution of the groundwater pathway to a total dose.

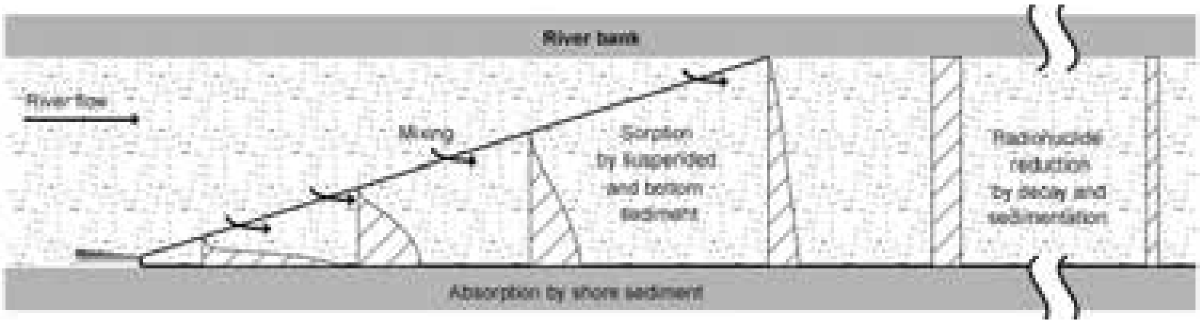

Figure 10-9: Processes affecting the movement of radionuclides from the point of discharge into a surface water body (IAEA, 2001).

- Flow processes, such as down-current transport (advection) and mixing processes (turbulent dispersion);
- Sediment processes, such as adsorption/desorption on suspended, shore/beach and bottom sediments, and down-current transport, deposition and re-suspension of sediment, which adsorbs radionuclides;
- Other processes, including radionuclide decay and other mechanisms that will reduce concentrations in water, such as radionuclide volatilization (if any).

The distribution of radionuclides into the surface water environment is thus much faster than in the case of radionuclides in groundwater and large volumes of surface water and sediment can potentially become contaminated. However, the radionuclide concentrations in a surface watercourse may be diluted, depending on the volume of water that will be discharged into the surface watercourse and the volume of water flowing past the point of discharge.

Several surface water streams might be influenced by the WRTRP (see Section 8.5), notably the Mooi River, Wonderfontein Spruit, the Loop Spruit, and the Leeuspruit. Some of the streams will experience a decrease in flow rate (e.g., Wonderfontein Spuit from a decrease in the discharge rate from K10), while others will experience an increase in flow rate (e.g., the Leeuspruit from the discharge of treated water from the AWTF for personal or agricultural use). The possibility of discharge into the Leeuspruit from the RTSF as an extension of the groundwater pathway cannot be excluded, but is unlikely from a radiological perspective.

The flow diagram in Figure 10-10 can be used to calculate the contribution of the surface water pathway to a total effective dose. Deposition of airborne radionuclides onto surface water bodies may contribute to the concentration of radionuclides in surface water. Factors that will influence the migration of radionuclides in surface water include surface water/groundwater interaction (e.g. discharge rates), mean annual flow rates, seasonal variation, and adsorption of radionuclides onto sediments. Depending on the radionuclide concentration of the surface water, as well as human habit and behavioural characteristics, various secondary pathways can contribute to a total effective dose (see Figure 10-10). These pathways are similar to those described for the atmospheric pathway, except that instead of deposition of airborne contaminants onto crops or soils, irrigation with contaminated water contributes to radionuclide concentrations in crops or soil.

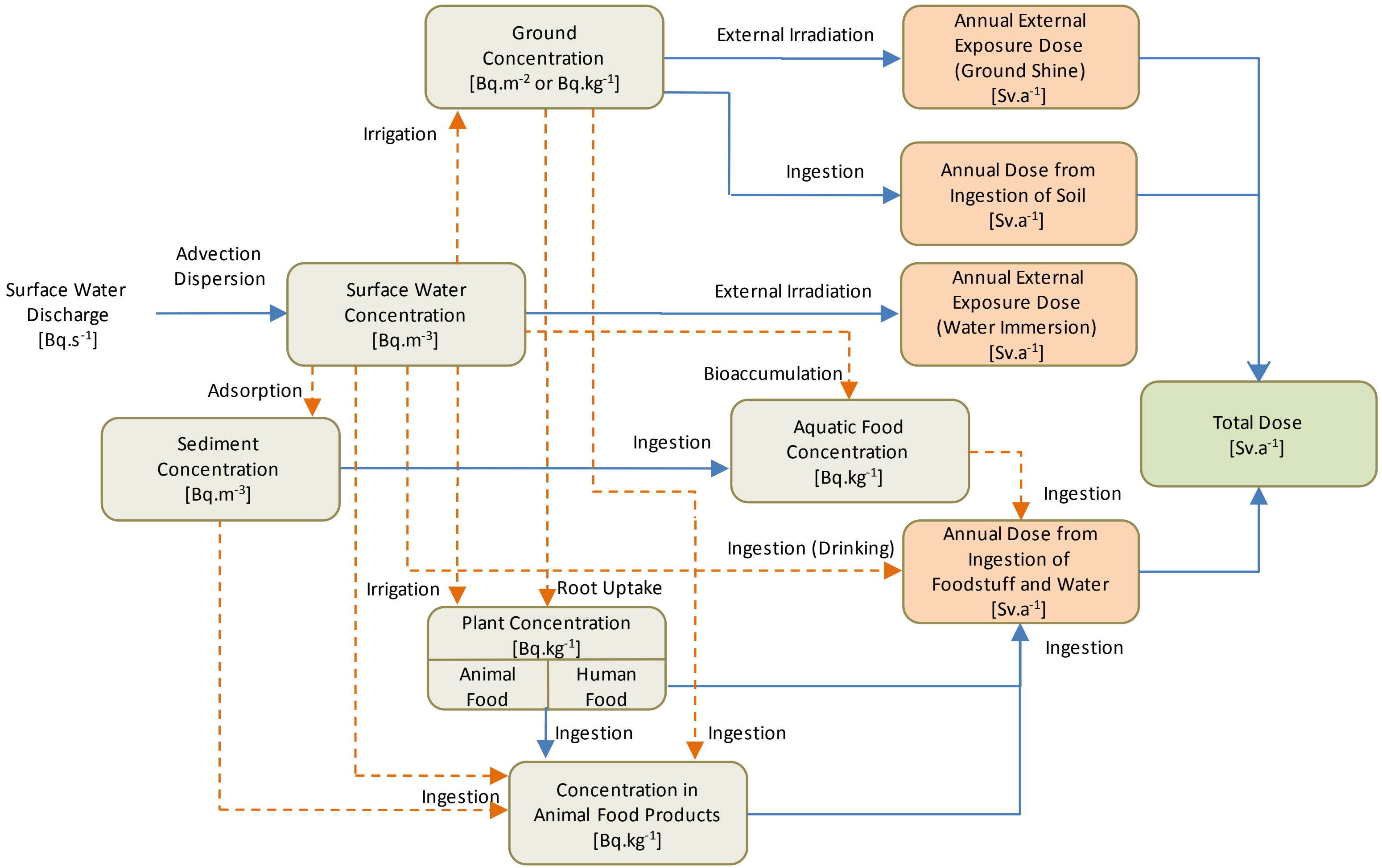

Figure 10-10: Features, processes and associated exposure modes that should be considered to calculate the contribution of the surface water pathway to a total dose.

Direct exposure to the contaminated surface water (e.g. swimming) also contributes to an external gamma radiation dose (water immersion). Adsorption of the contaminants onto the sediments will result in a transfer and accumulation (build up) of contaminants in the sediments (sediment concentration). Contaminants in the surface water can be transferred to aquatic animals such as fish (bioaccumulation), as well as from the ingestion of contaminated sediments.

10.2.4 External gamma radiation

Although not a contaminant in the usual sense, the inherent radiological properties of some of the primary sources of radiation may result in the continuous emission of gamma radiation (*external gamma radiation*). The main sources that are associated with external gamma radiation are the historical TSFs and the RTSF.

Gamma radiation from releases of contamination to the environment (secondary sources) is expected to be limited. It should be noted that the external gamma radiation would be the highest close to the source as radiation levels decrease by a factor of the square of the distance (i.e., inversely proportional to the square of the distance) away from the source (Martin, 2006).

10.3 Receptors

Receptors refer to members of the public that may potentially be subject to radiation exposure (i.e. a radiation dose) from the applicable sources and through the exposure pathways of concern. The aim is to identify a *critical group*, which is defined as one or more groups of people whose habits, location, age or other characteristics could cause them to receive a higher dose than the rest of the exposed population. Note that a radiological impact to members of the public (i.e., receptors) can only occur if a complete Source-Pathway-Receptor linkage exists.

Within the Source-Pathway-Receptor analysis approach, the identification of receptors cannot be done in isolation, but have to take into consideration the sources and pathways as well. It follows from Section 8.6 that the project area are widespread. The potential sources associated with the WRTRP are wide spread, from the Cooke TSF north of the N12 highway, to the Cooke 4 South TSF located south of the Ezulwini Operations, a distance to about 15 km. The RTSF is located the furthest south, about 20 km from the Ezulwini Operations, with the Driefontein 5 TSF the furthest west, about 30 km from the Ezulwini Operations. Within this area, the exposure population is large, with a diversity of human behavioural characteristics.

Section 8.6 provides a summary overview of the demographical characteristics of the area, as well as the associated land use and ownership as observed in the vicinity of the WRTRP. Land use conditions are characterised by urban and peri-urban residential areas, mining, agricultural (arable) and natural veld land use conditions. Agriculture is the dominant land use, followed by mining and residential land uses, with the latter accounting for less than

10% of the total land area. Some of these land use conditions borders the proposed or existing infrastructure, while others are further away.

An evaluation of the atmospheric pathways indicates that airborne contaminants will be the highest close to the sources, but will be dispersed and eventually reach urban and peri-urban residential areas, as well as commercial and smallholding agricultural areas. The groundwater flow regime generally conforms to local topographic features, which means that drainage will tends to be towards the surface water bodies. This may potentially affect peri-urban residential areas, as well as commercial and smallholding agricultural areas. Patches of land practicing commercial agricultural may be found in open areas.

The formal business and residential sectors include areas such as Randfontein, Mohlakeng, Carletonville, Westonaria, Venterspost, Rietvallei, Bekkersdal, Toekomsrus, Modderfontein, Hillshaven, Glenharvie, Simunye, Fochville, and mining towns such as Libanon and Waterpan. Residential land use comprises both formal and informal uses.

10.4 Conditions Leading to Public Exposure Condition

Given the nature of a mining and mineral processing operation, the definition of an exposure conditions is generally dependent on a number of factors. These include:

- Different exposure conditions may be relevant during different phases of the operation;
- Exposure conditions may vary depending on variations in the operational conditions on a site-specific basis;
- Different sources (e.g. point or diffuse sources) of radiation exposure may result in different exposure conditions to receptors;
- The importance of environmental (e.g. atmospheric, surface water or groundwater) or direct exposure pathways depends on the characteristics of sources and human behavioural characteristics; and
- Variations in human behavioural conditions near the operations may result in different exposure conditions.

Understandably, defining all exposure conditions to every potential receptor of radiation exposure at a mining and mineral processing operation is a near impossible task, especially with the purpose of evaluating the potential radiological consequences. For this reason, the approach adopted in this assessment is to revert to a discrete number of exposure conditions that capture the diversity and complexity associated with system under investigation.

While the SPR analysis approach to derive exposure conditions is systematic to some extent, a process of expert judgement is still required to combine the information on sources, pathways, and receptors into a well-defined and justifiable exposure condition. The following criteria are used for this purpose:

- Consistent with the ICRP principles, the radiological protection of each individual member of the public is of concern. However, it is judged impractical to derive an exposure condition for each of these individuals. The emphasis is therefore on the definition of exposure conditions that are representative of conditions associated with a wide range of individuals and human behavioural conditions;
- In doing so, the emphasis is also on the definition of exposure conditions that are representative of the group of individuals receiving the highest exposure (critical group). This does not suggest that other exposed groups are of lesser importance;
- As far as possible, actual conditions are considered, with the purpose to derive exposure conditions that are representative and realistic; and
- Where justified, a set of alternative, more hypothetical exposure conditions may also be defined. These hypothetical conditions tend to be more conservative and have the benefit that a wide range of conditions can be postulated. Often these exposure conditions would be representative of the most exposed individual, albeit hypothetical.

The key point of judgement whether the discrete set of exposure conditions are representative for the purpose of assessment, is whether potential receptors of radiation exposure are able to relate to at least one of these exposure conditions.

Depending on the timescales of concern, distinction can generally be made between off-site and on-site public exposure conditions. Onsite exposure conditions would assume that members of the public enters mine authorisation areas, whereas offsite exposure condition relates to conditions outside the mine authorisation area. The exertion of physical security measures during the operational period, means that in all likelihood onsite exposure condition are only applicable to the post-operational period. Note that public exposure conditions may be related to normal operating conditions, or to accident and incident conditions.

10.5 Definition of public exposure conditions for the WRTRP

The purpose of this section is to use the outcome of the Source-Pathway-Receptor analysis to define a discrete set of public exposure conditions to evaluate the radiological consequences of the WRTRP. It follows from the SPR analysis and the criteria presented in Section 10.4 that different public exposure conditions may be needed to evaluate the different components of the WRTRP and over the different timescales of concern.

The main areas of concern from a public radiation exposure perspective, are:

- The reclamation of the historical TSFs, which for the Initial Implementation phase of the WRTRP includes:
    - The Driefontein No. 3 TSF and Driefontein No. 5 TSF located within the operational boundaries of the Driefontein Operations; and

   - The Cooke TSF and Cooke 4 South TSF located within the operational boundaries of the Cooke Operations;
- The Ezulwini processing plant and Ezulwini North TSF located within the operational boundaries of the Ezulwini Operations;
- The CPP to be located within the operational boundaries of the Kloof Operations;
- The RTSF, RWD and AWTF to be located within the operational boundaries of the Kloof Operations.

10.5.1 Reclamation of Historical TSFs

The historical TSFs that will be reclaimed are located in areas characterised by mining, peri-urban, and agricultural farming land use conditions. The main environmental pathway of concern under current conditions are the atmospheric pathway, while seepage to the underlying aquifer and subsequent migration is a continuous but very slow process due to inherent geochemical processes. The reclamation of these facilities will result in the elimination of the TSFs as potential sources of radiation exposure during the post-operational period.

To assess the radiological impact of the reclamation of historical TSFs, a conservative **Commercial Agricultural Exposure Conditions** can be considered, illustrating the potential radiological impact before reclamation, and the subsequent positive radiological impact to members of the public after reclamation.

Note that although the reclamation process will eliminate the TSF itself as a groundwater pathway source, the saturated zone beneath the facility in all likelihood will still be contaminated, leaving a secondary source of contaminated groundwater.

10.5.2 Central Processing Plant

The CPP will be located in an area characterised by mining and agricultural farming land use conditions. The main environmental pathway of concern under current conditions is the atmospheric pathway, with release of dust (PM_{10}) containing naturally occurring radionuclides to the atmosphere.

To assess the radiological impact of the CPP as an additional source of radiation exposure in the area, a conservative **Commercial Agricultural Exposure Conditions** can be considered, illustrating the potential radiological impact after construction, which will constitute a negative radiological impact to members of the public. However, the only contributing pathway to the exposure condition would be dust inhalation from PM_{10}, since TSP that introduce secondary pathways after deposition, and radon gas are not released from the CPP stacks.

10.5.3 Regional Tailings Storage Facility

The RTSF will be located in an area characterised almost exclusively by commercial agricultural farming land use conditions, with the main environmental pathway of concern the atmospheric (dust and radon) and groundwater pathways. Fochville town is located to the west, but are too far to be influenced by atmospheric or groundwater pathway releases.

To assess the radiological impact of the RTSF as an additional source of radiation exposure in the area, a conservative **Commercial Agricultural Exposure Conditions** can be considered, illustrating the potential radiological impact after construction, which will constitute a negative radiological impact to members of the public.

Note that the contribution from the atmospheric pathway will be from commissioning, while any potential contribution from the groundwater pathway will only manifest itself as a potential radiological impact during the post-operational period.

10.5.4 Advance Water Treatment Facility

The AWTF itself was excluded as a source and therefore does not lead to a public radiation exposure condition. However, the water released to the environment after treatment may. Similar to the RTSF, the AWTF will be located in an area characterised almost exclusively by commercial agricultural farming land use conditions. The water released to the Leeuspruit may be used for different purposes, but for consistency a conservative **Commercial Agricultural Exposure Conditions** can be considered for the purpose of the assessment, assuming a farmer extract water from the Leeuspruit as his only source of water to sustain his farm system. This means that the surface water pathway is the main pathway of concern.

10.5.5 Ezulwini Processing Plant and Ezulwini North TSF

Both the Ezulwini Plant and Ezulwini North TSF were identified as potential sources of radiation exposure under current operational condition, with additional processing and deposition associated with the WRTRP still within the authorisation conditions for the respective facilities. As such, no additional sources of radiation exposure are introduced.

For consistency as appropriate, a conservative **Commercial Agricultural Exposure Conditions** will be considered for the purpose of the assessment to illustrate current radiological impacts and for comparison purposes.

10.5.6 Commercial Agricultural Exposure Condition

The purpose of the Commercial Agricultural Exposure Condition is to evaluate the radiological consequences to members of the public practicing commercial farming near the different components of the WRTRP. This means that this exposure condition relates to any commercial farming activity for the conditions and assumptions presented below.

Note that this is not the only exposure condition relevant or suitable for the area, but are conservative and representative of a very wide range of conditions due to the exposure pathways and exposure routes included. Examples of other exposure conditions that may be considered include a Residential Exposure Condition, Urban- or Peri-Urban Exposure Conditions, or an Area Dweller Exposure Condition. All these examples would constitute variations to the conditions assumed for the Commercial Agricultural Exposure Condition.

However, the conditions assumed for the latter is the most conservative. Variation in exposure conditions may be treated as part of the sensitivity and uncertainty analysis.

The main contributor to a total effective dose is from the atmospheric, groundwater, surface water (where appropriate) and associated secondary pathways. This resulted in contributions from external gamma radiation, internal exposure following ingestion of contaminated water, soil and crops, and internal exposure from the inhalation of airborne radon and LLα dust.

In addition to the conditions and assumptions presented above, the following are assumed for the purpose of the Commercial Agricultural Exposure Condition:

- The exposure groups (farmer and farm workers) consist of members of the public from all age groups.
- The exposure group maintain a commercial farm system consistent of fruits, vegetables and cereal (mealies). It is conservatively assumed that the farm contributes 100% to their annual consumption rate.
- The exposure group keep animals in the form of chickens, sheep and cattle. These serve as a source of protein in the form of eggs, milk and meat. For the purpose of the assessment, it is conservatively assumed that it contributed to 100% to their annual consumption rate.
- Some food preparation methods are used (e.g. boiling) that may contribute to a reduction in radioactivity concentrations. However, for the purpose of this assessment it is assumed that not food preparation takes place.
- Consistent with the guidelines presented in RG-002 (NNR, 2013b), the indoor and outdoor occupancy factors assumed for the purpose of the assessment is 5,700 and 3,100 hours per annum.

The conceptual model for the Commercial Agricultural Exposure Condition is presented in Figure 10-11 and Figure 10-12 using a flow diagram and Interaction Matrix, respectively.

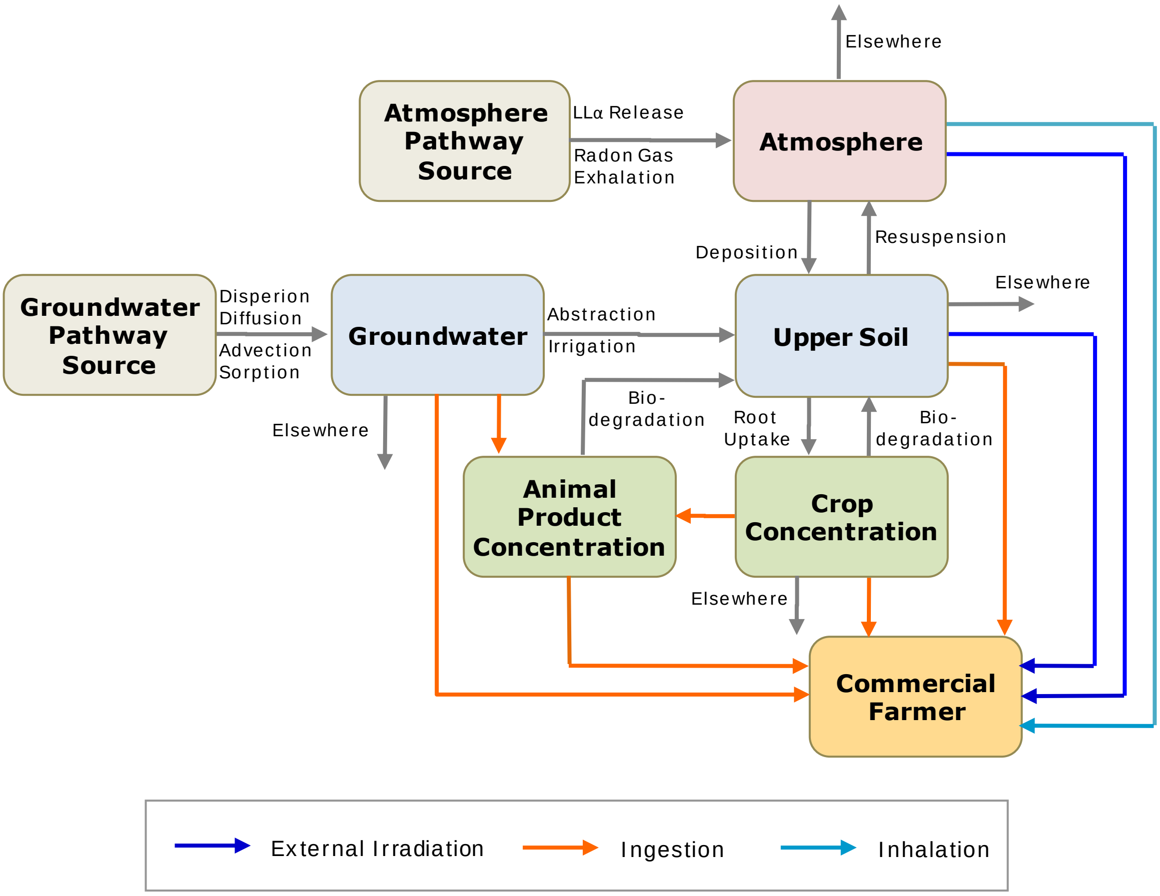

Figure 10-11: Conceptual flow diagram of the exposure pathways associated with the Commercial Agricultural Exposure Condition.

	1	2	3	4	5	6	7	8	9	10
A	Atmospheric Pathway Sources		LLα Suspension Dispersion	Radon Exhalation Dispersion						
B		Groundwater Pathway Sources			Advection Dispersion Diffusion Sorption					
C			Atmosphere LLα Conc.			Deposition	Deposition Interception		Inhalation External Exposure	Dispersion
D				Atmosphere Radon Conc.					Inhalation	Dispersion
E					Water (Borehole)	Deposition	Interception	Ingestion	Ingestion	Advection Dispersion Diffusion Sorption
F			Re-suspension			Upper Soil	Root Uptake Crop Contam.	Ingestion	External Exposure Ingestion	Erosion Leaching

G						Bio-degradation	Crops	Ingestion	Ingestion	Washed Away Weathering
H						Bio-degradation Excrement		Animals	Ingestion	
					Abstract	Irrigation Tilling Ploughing	Plant crops Food preparation	Feed	Commercial Farmer	Excrement
J										Elsewhere

Figure 10-12: Conceptual Interaction Matrix of the exposure pathways associated with the Commercial Agricultural Exposure Condition.

Exposure routes associated with the Commercial Agricultural Exposure Condition include radon gas and LLα inhalation, as well as ingestion of contaminated groundwater or surface water, crops and animal products (meat, eggs and milk). Inadvertent soil ingestion is also assumed. Contributions to the total effective dose from external gamma radiation is also expected from airborne LLα (cloud immersion) and radionuclides deposited on the upper soil layer (ground shine).

Radon gas and LLα released from the atmospheric pathway sources are dispersed into the environment, contributing to an airborne radionuclide concentration. Some of the airborne radionuclides are deposited onto the crops (fruits, vegetables and cereal), contributing to a crop concentration, as well as on the upper soil surface, contributing to a soil concentration. Root uptake processes transfer some of the radionuclides from the soil to the crops, contributing to a crop concentration.

Radionuclides leach from the groundwater pathway sources into the underlying aquifer, from where it dispersed into the groundwater environment (groundwater concentration). Members from exposure group uses groundwater abstracted from a borehole for their own consumption and to maintain a commercial farm system (i.e. irrigation and water supply), consisting of crops, poultry and cattle. Radionuclides in the water are deposited onto the crops, contributing to a crop concentration, as well as on the upper soil surface, contributing to a soil concentration. Root uptake processes transfer some of the radionuclides from the soil to the crops, contributing to a crop concentration. Animals consume the water and crops, contributing to the animal product concentration.

Note that, as illustrated in Figure 10-11 and Figure 10-12, biodegradation of crop material may also contribute to the upper soil concentration, while resuspension of deposited dust may contribute to the airborne activity concentration. Also illustrated in Figure 10-11 and Figure 10-12, is the transfer of some of the radioactivity released from the atmospheric pathway sources, to “elsewhere” through processes such as dispersion, leaching, washing, weathering and excrement. “Elsewhere” as used here refers to a place where humans will not be affected by the radionuclides of concern. Water released to the Leeuspruit, *groundwater* in Figure 10-11 and Figure 10-12 are replaced with *surface water*.

10.5.7 Accidents and Incidents

An exposure condition for Accident and Incident represents a series of possible unexpected exposure situations that may occur during the operational phase of the WRTRP, but that falls outside the normal operating conditions. This exposure condition is not directed at a specific receptor group. Given the nature of these events, the impact of the Accident and Incident Exposure Condition is directed towards the surface environment, notably the surface soils, surface water bodies and sediments. The following events are associated with the Accident and Incidents Exposure Condition:

- Spillages from storage ponds (e.. RWD);
- Pipeline burst (tailings or water spillages on surface soils or surface water bodies); and
- Controlled or uncontrolled releases of water to the environment.

Depending on the specific event, the radiological consequences may be evaluated on a qualitative or quantitative basis (see Section 16).

11 Mathematical Model Development

Mining and mineral processing operations can be complex with a diversity of sources, pathways and receptors that have to be considered in an integrated manner in the radiological safety assessment process. Different approaches with varying levels of mathematical complexity can be followed to evaluate different elements or components of the integrated system. These approaches ranging from a set of algebraic equations implemented in spreadsheets, to complex two- or three-dimensional differential equations implemented in commercial software.

The assessment framework presented in Figure 5-1, depicts model development as consisting of a number of individual steps, the result being the implementation of the conceptual and associated mathematical models in appropriate computer software or tools, often referred to as a *computer model*. These steps in relation with other elements in the assessment framework, is depicted in Figure 11-1, which emphasises the fact that model development and implementation for a specific set of scenarios and exposure conditions are subject to the current understanding of the system with a continuous feed of model parameter values.

The assessment framework makes provision for the use of *Process Level Modelling* and a *System Level Modelling* (see Figure 5-1). The purpose of this section is to provide a brief overview of the Process and System Level Modelling, as well as the mathematical expressions used as part of the System Level Model implementation.

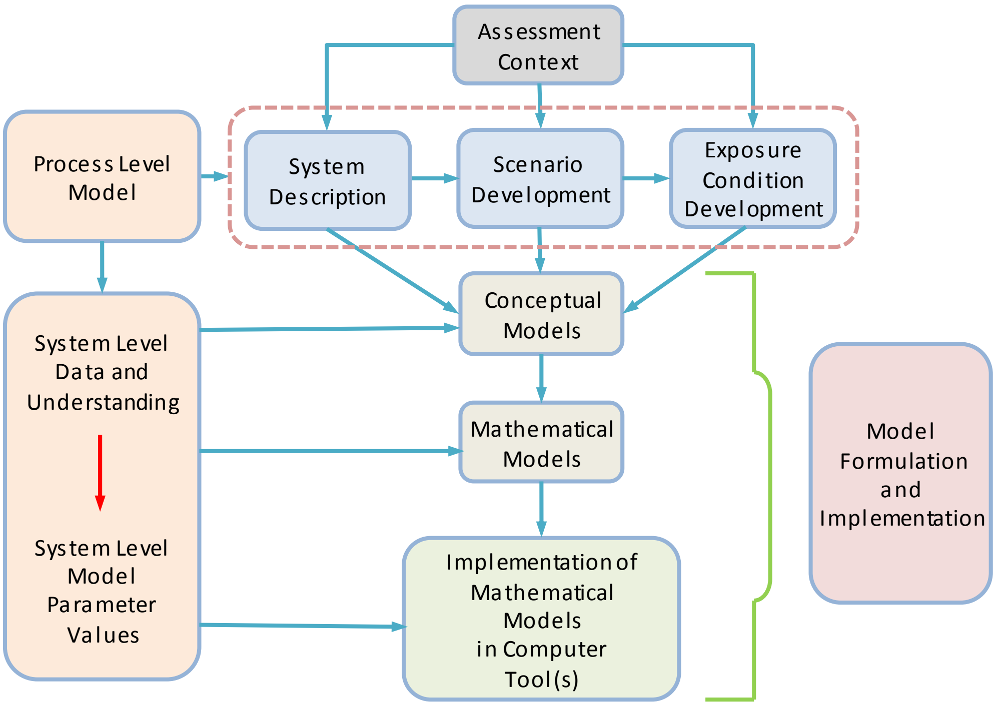

Figure 11-1: The model development process in relation to other elements of the assessment framework presented in Figure 5-1.

11.1 Process Level Modelling

The release and subsequent migration of naturally occurring radionuclides into and through the environment as a function of time and space is governed by complex partial differential equations. Due to their complexity and lack of analytical solutions, numerical methods are often required to solve these equations. *Process Level Modelling* is process and pathway (e.g., atmospheric, surface water and groundwater) specific and generally performed at a much greater level of detail than for example, *System Level Modelling*. For this reason, specialists are often used to perform *Process Level Modelling*. Examples of Process Level Modelling performed for the WRTRP is the groundwater and air quality impact assessment studies (Digby Wells Environmental, 2015g; h).

The level of detailed information and system behaviour understanding that can be generated through *Process Level Modelling* are significant, which underlines its importance in the overall safety assessment framework. While this enables a very detailed consideration of environmental processes, it also requires considerable resources to develop and execute these models. For this reason, it is often, at least at present, not viable to use *Process Level Modelling* directly in integrated safety assessment analysis.

Figure 5-1 shows that within the assessment framework, *Process Level Modelling* provide input into the system description, as part of the overall understanding of the system behaviour. It also assists with the definition and justification of exposure conditions, especially in terms of understanding the spatial and temporal impact of particulates and contaminants released to the environment.

11.2 System Level Modelling

The aim of *System Level Modelling* within the safety assessment framework (see Figure 5-1) is to integrate as many as possible of the total system components into an integrated model, with the purpose to quantify the total radiological impact. A compartment model approach is often used for this purpose to represent the migration and fate of contaminants in the environment. During the process, relevant information and input values are abstracted from the *Process Level Modelling* in support of the *System Level Model*.

The use of a compartment model approach places two main constraints on the mathematical representation of a total system (Little *et al.*, 2003).

The first constraint is that the system has to be devided into a series of compartments. Using the compartment modelling approach, a system may be represented by breaking it down into compartments that can correspond to the components identified in the conceptual model. It is assumed that, as soon as a contaminant enters a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment. Each compartment must be chosen to represent a system component for which this assumption is reasonable.

The second constraint is that processes resulting in the transfer of contaminants from one compartment to another need to be expressed as transfer coefficients that represent the fraction of the activity in a particular compartment transferred from that compartment to another per unit time. The mathematical representation of the intercompartmental transfer processes takes the form of a matrix of transfer coefficients that allow the compartmental amounts to be represented as a set of first order linear differential equations.

For the i^{th} compartment, the rate at which the inventory of radionuclides in a compartment changes with time is given by (Little *et al.*, 2003):

$$\frac{dN_i}{dt} = \left(\sum_{j \neq i} \lambda_{ji} N_j + \lambda_N M_i + S_i(t)\right) - \left(\sum_{j \neq i} \lambda_{ij} N_i + \lambda_N N_i\right)$$

where *i* and *j* indicate compartments, *N* and *M* are the amounts (Bq) of radionuclides *N* and *M* in a compartment (*M* is the precursor of *N* in a decay chain). *S(t)* is a time dependent external source of radionuclide *N* (Bq y^{-1}). Transfer and loss rates are represented by λ. λ_N is the decay constant for radionuclide *N* (y^{-1}) and λ_{ji} and λ_{ij} are transfer coefficients (y^{-1}) representing the gain and loss of radionuclide *N* from compartments *i* and *j*. For simplicity, the above equation assumes a single parent and daughter. However, compartmental modelling software such as Ecolego® allows the representation of multiple parents and daughters.

The solution of the matrix of equations given above provides the time-dependent inventory of each compartment. Assumptions for compartment sizes then result in estimates of concentrations in the corresponding media from which doses/intakes can be estimated.

System Level Modelling for the WRTRP will be implemented in Ecolego® Version 6 (http://ecolego.facilia.se/ecolego/show/HomePage), with a clear distinction between the sources, pathways and receptors. For this purpose, an abstraction of information from the process level model is needed in terms of pathway specific parameter values. Ecolego® uses a compartment model approach to represent the migration and fate of contaminants in the environment. The system is discretised into a series of compartments and sub-compartments that correspond to the components identified in the conceptual model. It is assumed that, as soon as a contaminant enters a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment.

Note that it is not always possible or practical to include all system components into one *System Level Model*. The contribution from the atmospheric pathway, for example, is dynamic and the radiological impact to members of the public may be from the first day of operation (i.e. present day conditions. The contribution of the groundwater pathway, on the other hand, is slow and the potential radiological impact may only occur in the far future (e.g. hundreds of years from now). The timescales of concern over which the potential radiological impact to members of the public will occur to thus very different.

11.3 Model Implementation for the WRTRP

The exposure conditions defined for the purpose of the assessment requires that the contribution of the atmospheric and groundwater pathway to a total effective dose be quantified. For this purpose, a combination of *Process Level Modelling* and *System Level Modelling* is used, with the groundwater and atmospheric pathways considered separately (i.e. decoupled).

11.3.1 Groundwater pathway

Model implementation of the groundwater pathway consists of a *Process Level Model* that describe the saturated groundwater flow regime, and a *System Level Model* that describe the mass transport of naturally occurring radionuclides.

The development of the *Process Level Model* for the groundwater pathway is a separate specialist study, (Digby Wells Environmental, 2015g) that provides as output the steady state and potential transient piezometric head distribution. From the piezometric head distribution, the groundwater flow directions and the associated groundwater flow velocities (Darcy velocities) under steady state or transient conditions can be derived. The hydrogeological conceptual, mathematical, and associated numerical model is described in detail in Digby Wells Environmental (2015g) and not repeated here.

The *System Level Model* considers the potential leaching of contaminants from the groundwater sources, the downward migration of the contaminants through the unsaturated zone to the underlying aquifer, the mixing of these contaminants with passing groundwater, and the subsequent migration of the contaminant plume through the aquifer to a receiving water body (e.g. river) of borehole. The groundwater flow direction and associated Darcy velocities derived from the *Process Level Model* serves as input into the *System Level*

Model. The *System Level Model* provides as output the time dependent breakthrough curve of naturally occurring radionuclides at a point of interest (in units of $Bq.L^{-1}$). The *System Level Model* can thus be coupled with the various dose models to calculate the radiological impact through the groundwater pathway.

11.3.2 Atmospheric Pathway

The development of the *Process Level Model* for the atmospheric pathway is separate specialist studies (Digby Wells Environmental, 2015h; Parc Scientific, 2015) that describes the relevant conceptual, mathematical, and numerical models. The description of these models will not be repeated here. Model implementation for the atmospheric pathway consists of a *Process Level Model* based on the prevailing meteorological conditions and the source terms release rates from the atmospheric pathway sources that provides the following as output:

- The spatial distribution (at grid points) of the annual average airborne dust concentration (PM_{10}) in the atmosphere (units of $\mu g.m^{-3}$);
- The special distribution (at grid points) of the annual average dust deposition rate of Total Suspended Particulates (TSP) into the environment (units of $mg.m^{-2}.day^{-1}$); and
- The spatial distribution (at grid points) of the annual average airborne radon and thoron concentrations (units of $Bq.m^{-3}$).

One limitation of atmospheric pathway *Process Level Model* (at present) is that it is time independent, and only represents the results for a given source term as input values. For this reason, the results are presented as annual averages, or as maximums. A *System Level Model* may not be subject to these limitations.

The spatial distribution of the annual average airborne radon concentrations can be used directly to assess the contribution of radon inhalation to a total effective dose. The spatial distribution of PM_{10} and TSP still have to be multiplied with the radionuclide activity concentrations associated with the different sources. If the total contribution is from one source, then it is a simple case of multiplying the PM_{10} ($\mu g.m^{-3}$) and TSP ($mg.m^{-2}.day^{-1}$) values with the radionuclide specific activity concentration ($Bq.g^{-1}$) to get the radionuclide specific airborne activity concentration ($\mu Bq.m^{-3}$) and deposition rate ($mBq.m^{-2}.day^{-1}$).

If the contribution is from multiple sources, then the relative contribution of each source to the PM_{10} and TSP concentrations have to be multiplied with the radionuclide specific activity concentration of each source. The resulting values then have to be summed over all sources to get the total radionuclide specific airborne activity concentration and deposition rate. The output from this process can then be coupled with the dose models to calculate the radiological impact through the atmospheric pathway.

11.3.3 Dose Assessment Models

The processes described above is used to quantify the radionuclide specific activity concentrations in different environmental compartments (e.g. atmosphere and underlying aquifer). These radionuclides may be further transferred and distributed to other biosphere compartments (e.g. surface water, surface soils, grass, sediments, animal products, etc.). Human interaction with these compartments will result and contribute to a total effective dose, subject to assumptions and conditions in terms of their interaction (e.g. the use of animal products as a source of food). The dose models used for this purpose include the following:

- The change in soil activity concentration with time due to deposition and irrigation;
- Indoor and outdoor airborne radon concentrations released from a surface source; and
- The total effective dose to members of the public due to direct ingestion of contaminated water, soil, fish, secondary crop and animal products, direct inhalation of contaminated airborne dust (LLα) and radon gas, as well as from external exposure to contaminated air, soil, and water.

12 Consequence Analysis: Radiation Dose Assessment

Within the conceptual assessment framework presented in Figure 5-1, the purpose of the consequence analysis is to derive quantitative criteria as basis for the radiological impact assessment presented in Section 14. Consistent with the assessment endpoints (see Section 6.4.1), the total effective dose calculated for each exposure condition is used as quantitative criteria.

Distinction is made between the different Mining Right areas (i.e., Cooke, Ezulwini, Kloof and Driefontein), each with its own CoR, as well as the potential radiological impact during the different operational phases of the WRTRP (i.e., pre-operational (current) conditions, operational conditions, and post-operational conditions). A further distinction is made between potential contributions from the different pathways. The potential cumulative impact is discussed in Section 0.

12.1 Potential contribution from the groundwater pathway

Due to the sensitivity of groundwater as a resource, the contribution of the groundwater pathway to the total effective dose is a sensitive issue, especially for the agricultural sector. The Commercial Agricultural Exposure Condition defined for the purpose of the radiological impact assessment is cautious-realistic for the local site conditions, and include potential contributions from the aquatic (mostly groundwater) and atmospheric pathways. The reason for the inclusion of the groundwater pathway is mainly because the possibility that groundwater is used for personal use and to sustain agricultural activities cannot be excluded.

As far as the WRTRP is concern, groundwater resources near the TSFs are of concern. Other facilities (e.g., thickeners, BWSF, processing plant, etc.) applies a zero water release policy and consequently the probability of groundwater contamination is insignificant. It was noted in Section 10.3 that a radiological impact is only possible if a complete Source-

Pathway-Receptor linkage exists over the timescale of concern. This means that the groundwater pathway will only make a contribution to the radiological impact if receptors (i.e., members of the public) abstract and use contaminated groundwater originating from the specific source.

It is a well-known phenomenon that radionuclides leach from TSFs into the underlying aquifer system. This is a slow process that is a function of the facility itself and its inherent radiological properties, the dissolution of radionuclides in the infiltrating water, the local meteorological conditions (e.g. precipitation and evapotranspiration), as well as various hydrological and geochemical processes. Similarly, the lateral migration of radionuclide contaminant plume in the aquifer to a point of abstraction is a very slow process, controlled by similar hydrological and geochemical processes. These processes will continue as long as the source (in this case the TSF) remains at surface.

Once the TSF is removed (e.g. through reclamation), leaching to the underlying aquifer will be terminated, but leaving a secondary source of contaminated groundwater at the footprint of the TSF, from where it will continue to migrate downgradient in the direction of groundwater flow. In this case, the potential impact of the TSF downgradient will be less, oppose to a situation where the TSF remains at surface, because the primary source of contamination was removed. However, the extent of the groundwater contamination beneath the TSF can only be established once removed.

It can be illustrated (van Blerk, 2015b) that even using very conservative assumptions, a radionuclide contaminant plume may take thousands of years to reach a borehole located 500 m from the TSF (see Table 12-1 and Figure 12-1). If one assume the RG-002 (NNR, 2013b) water ingestion rates for the different age groups, then the groundwater activity concentrations in Figure 12-1 translate into the water ingestion doses as presented in Figure 12-2.

The result presented in Figure 12-1 and Figure 12-2 is for a TSF that remains at surface and intact for the duration of the simulation period. If the TSF is removed, the resulting activity concentrations and water ingestion dose will be lower. In this case the end land use condition of the rehabilitated footprint area need to consider the potential presence of a contaminated groundwater plume beneath the historical TSF area.

It is important to note that these calculations are illustrative, and variations are expected as site and facility specific conditions vary. Higher activity concentration, for example, will result in higher doses, while more realistic (less conservative) distribution coefficients (K_d-values) will reduce doses. However, it is unlikely that groundwater leaching from a TSF will make a contribution to the total effective dose within a period of 1000 years since commissioning.

Table 12-1: Parameter values assumed for a TSF, unsaturated zone, and saturated zone to illustrate the contribution of the groundwater pathway (van Blerk, 2015b).

Unit	Parameter	Unit	Value
Source (TSF)	Area of the TSF	m^2	3.0E+06
	Length and width of the TSF	m	1,732

	Thickness of the TSF	m	40
	Dry Bulk Density of Tailings	$kg.m^{-3}$	1,800
	Infiltration Rate into TSF (3% of MAP of 693 mm)	$m.a^{-1}$	0.0208
	Volumetric Moisture Content	-	0.3
Unsaturated Zone	Dry Bulk Density	$kg.m^{-3}$	2,000
	Infiltration Rate Through Unsaturated Zone	$m.a^{-1}$	0.0208
	Volumetric Moisture Content	-	0.3
	Thickness of Unsaturated Zone	m	1
Aquifer	Aquifer Thickness	m	40
	Distance to Borehole (flow tube)	m	500
	Darcy Velocity in Direction of Flow	$m.a^{-1}$	16
	Dry Bulk Density	$kg.m^{-3}$	2,000
	Aquifer Porosity	-	3%

The contribution of the groundwater pathway will again be considered as part of the radiological impact of the RTSF (see Section 12.4.3.1).

12.2 Cooke operations

The WRTRP activities for the Cooke Operations that are of relevance from a radiological impact assessment perspective are the reclamation of the Cooke and Cooke 4 South TSFs. It is estimated that the reclamation process will last for 16 years, after which the site will be rehabilitated and cleaned to levels suitable for future land use conditions still to be determined.

12.2.1 Current radiological impact

Under current operational conditions and over the timescales of concern, the major contribution to a total effective dose from the reclamation of the two TSFs for a Commercial Agricultural Exposure Condition, is through the atmospheric pathway. The groundwater pathway, although important, does not make a significant contribution to the total effective dose over the timescale of concern, mainly because a complete Source-Pathway-Receptor linkage does not exist over the timescales of concern. The results presented in Section 12.1 confirmed this notion.

A recent study (van Blerk, 2015c) illustrated that the major contribution through the atmospheric pathway is from radon gas inhalation, with the main areas of impact in a south-south westerly direction from the two TSFs. Figure 12-3 depicts the total effective dose to adults for the Commercial Agricultural Exposure Condition. From Figure 12-3 it is clear that the current radiological impact from the TSFs is highest very close to the TSFs, but decrease significantly with distance away from the TSF.

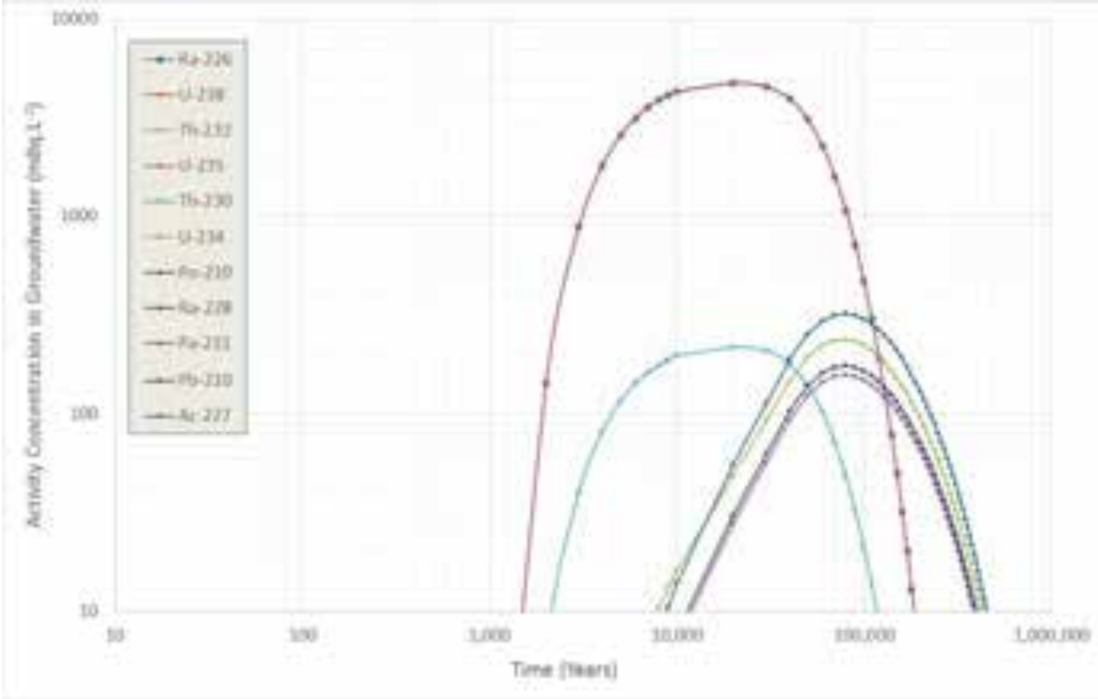

Figure 12-1: The simulated activity concentration in groundwater abstracted from a borehole 500 m from the TSF, using the parameter values listed in Table 12-1 (van Blerk, 2015b).

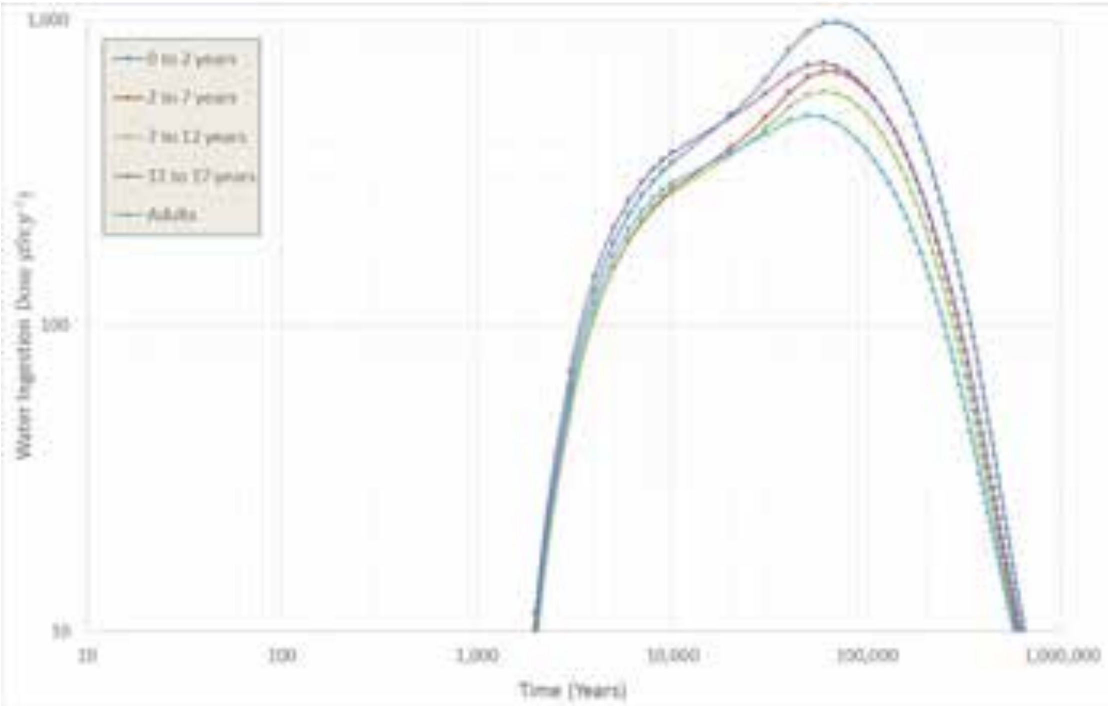

Figure 12-2: The simulated water ingestion dose to the different age groups, using the parameter values listed in Table 12-1 and the activity concentrations in Figure 12-1 (van Blerk, 2015b).

The direction and extent of the radiological impact is controlled by the prevailing meteorological conditions used in the atmospheric dispersion modelling. The contribution from the Cooke and Cooke 4 South TSFs to the total effective dose is evident from Figure 12-3.

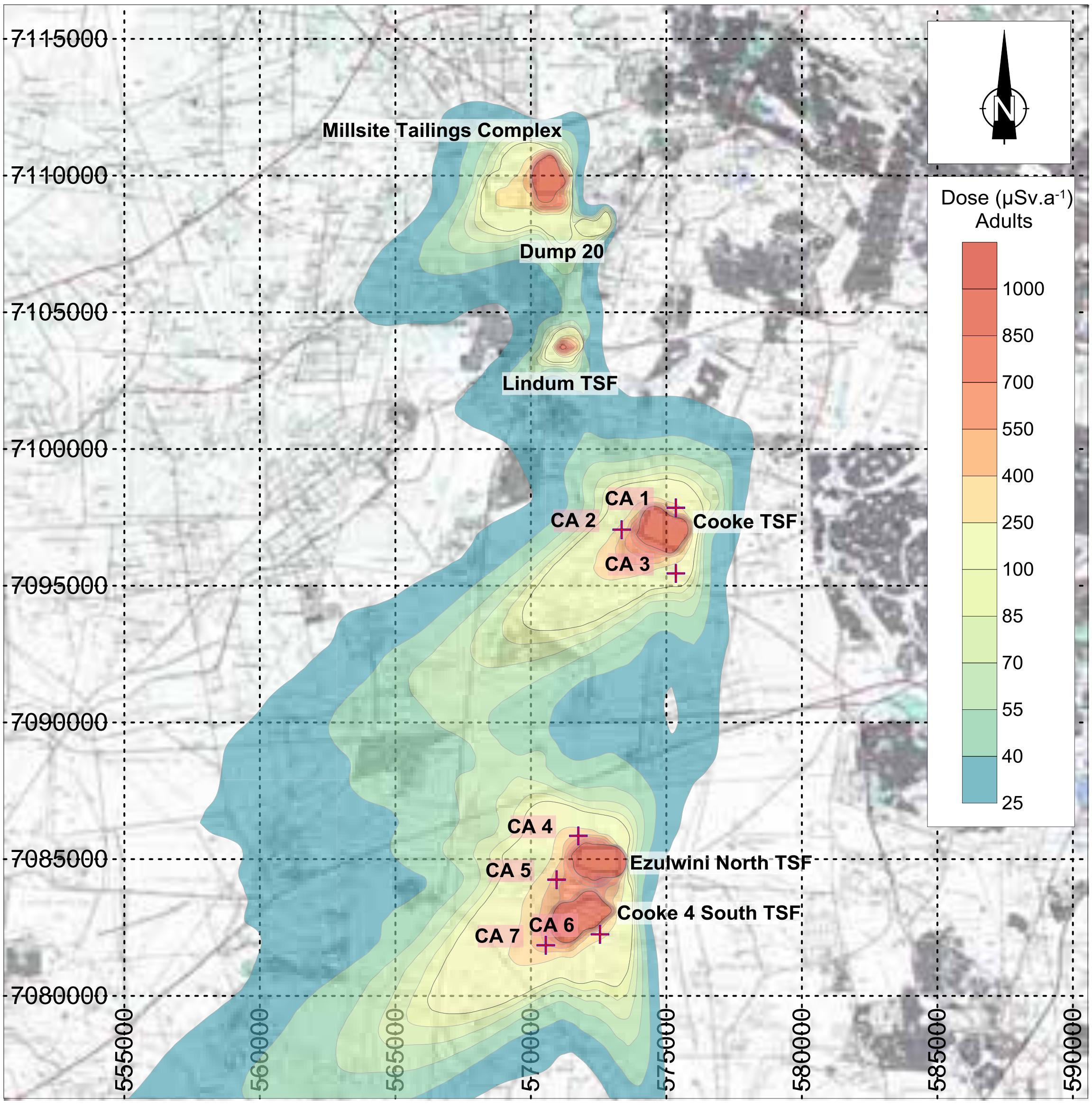

Figure 12-3: Dose isopleths for the adult age group depicting the contribution of the Commercial Agricultural Exposure Condition before the implementation of the WRTRP (van Blerk, 2015c).

12.2.2 Radiological impact during retreatment

The retreatment of the Cooke and Cooke 4 South TSFs is a wet process using hydraulic sluicing. This means that any contribution from the atmospheric pathway for that section of the TSF will be eliminated. Effectively, the source term is reduced, which means that the potential radiological impact through the atmospheric pathway is reduced accordingly. One can therefore expect the radiological impact also to be less during the reclamation process.

The contribution through the groundwater pathway is not expected to change significantly, if at all. The use of hydraulic sluicing during retreatment means that additional water is present that might increase the source term release rate to the underlying aquifer. However, this will not influence the migration of radionuclides in the aquifer itself, which was illustrated to be an inherently slow process (see Section 12.1). Storm water management practices will be applied during the retreatment process, which means that excess water will be channelled back into the system. Water will not be released from the site. This implies that the potential radiological impact during retreatment will be similar to those under current (baseline) conditions, or less.

12.2.3 Future radiological impact

The assumption is that once the footprints of the Cooke and Cooke 4 South TSFs has been retreated, then the site will be rehabilitated and cleaned to levels suitable for the anticipated future land use condition. This means that all the tailings material that contains naturally occurring radionuclides will be removed, and effectively remove the source of radiation exposure. The implication is that the contribution of these two TSFs in Figure 12-3 will be eliminated, resulting in a significant positive radiological impact to members of the public in the vicinity of the TSFs. This is illustrated in Figure 12-4, from which it is clear that the total effective dose in the vicinity of the Cooke TSF is reduced to insignificant levels, while the removal of the Cooke 4 South TSF means that the only significant contribution in the vicinity of the Ezulwini Operations that remains is from the Ezulwini North TSF.

12.3 Ezulwini Operations

The WRTRP activities associated with the Ezulwini Operations that are of relevance from a radiological impact assessment perspective (see Section 10.1) is the additional processing of uranium concentrate from the CPP at the Ezulwini Processing Plant, and additional deposition of processed material at the existing Ezulwini North TSF.

12.3.1 Current radiological impact

The major contribution to a total effective dose from the Ezulwini Operations for a Commercial Agricultural Exposure Condition, is through the atmospheric pathway. Figure 12-3 also depicts the total effective dose to adults for the Commercial Agricultural Exposure Condition from the Ezulwini Operations, with the Ezulwini North TSF the main contributor. The contribution of the processing plant and the ventilation shaft is insignificant relative to that of the TSF. From Figure 12-3 it is again clear that the current radiological impact from the TSF is at its highest very close to the source, but decrease significantly with distance away from the TSF.

12.3.2 Future radiological impact

Figure 12-4 depicts the total effective dose to adults for the Commercial Agricultural Exposure Condition, with the Ezulwini North TSF the only contributing source in the vicinity of the Ezulwini Operations. These results were derived using the assumed activity concentrations for the Ezulwini North TSF as listed in Table 9-9, which suggests relatively high concentrations of Ra-226, Pb-210 and Po-210. These isotopes make significant contributions to the total effective dose.

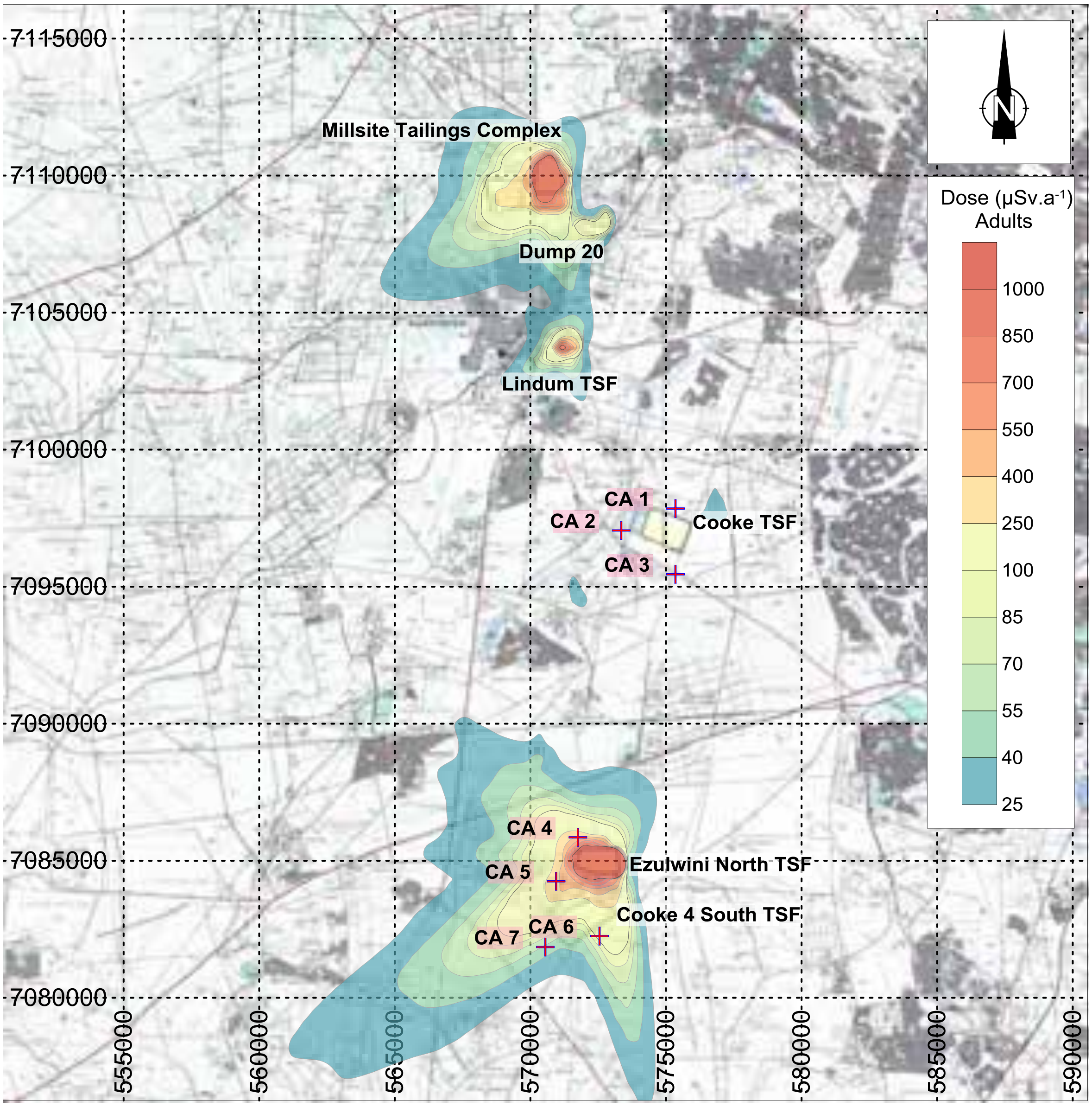

Figure 12-4: Dose isopleths for the adult age group depicting the contribution of the Commercial Agricultural Exposure Condition after the implementation of the WRTRP.

One can assume that the additional tailings material to be deposited at the Ezulwini North TSF will contain lower concentrations of most of the isotopes. Not only will a significant portion of the uranium be extracted, the activity concentration of Ra-226 and Pb-210 in the tailings to be reprocessed is generally lower (see Table 9-11), hence a reduction in radionuclide concentrations that can be dispersed into the atmosphere. However, this tailings material will only cover a portion of the Ezulwini North TSF and thus it is difficult to quantify the potential reduction in total effective dose from the total TSF, and for how long this condition will apply. At best it can be assumed that the exposure levels will be similar or less.

12.4 Kloof Operations

The WRTRP activities associated with the Kloof Operations that are of relevance from a radiological impact assessment perspective (see Section 10.1) include the operation of the AWTF, the RTSF with its associated components (e.g., RWD), and the operation of the CPP.

The AWTF, the RTSF and the CPP are new facilities that still has to be constructed. This means that there is no radiological impact associated with these facilities and associated components at present. The radiological assessment presented here is thus prospective in nature.

12.4.1 Radiological Impact associated with the AWTF

The AWTF itself does not pose a radiological impact to members of the public. The radiological impact associated with the AWTF is the treatment and the subsequent release of treated water to the Leeuspruit for human usage and consumption. The radiological properties assumed for the treated water was derived and discussed in Section 9 (see Table 9-16).

To evaluate the radiological consequence of the treated water, it is assumed that the water is being used as part of the Commercial Agricultural Exposure Condition. Table 12-2 presents the pathway specific contribution to the total effective dose using *untreated water* from the RWD, while Table 12-3 presents the resulting pathway specific contribution to the total effective dose. From Table 12-3 it is clear that the total effective dose contribution is minimal and well below the dose constraint of 250 µSv per year for all age groups. Given the conservative nature of the Commercial Agricultural Exposure Condition, the radiological impact of the AWTF is expected to be insignificant, *if the proposed targets for treatment can be achieved and sustained*. The major contribution is from direct water ingestion (as expected), with trivial contribution from the secondary pathways (assuming a 100-year irrigation period). On the other hand, a direct comparison between Table 12-2 and Table 12-3 suggests that the radiological impact of untreated water is significant.

12.4.2 Radiological Impact associated with the CPP

The CPP is designed and will be operated on a zero water release policy, which means that all run-off from the facility will be contained as diverted back into the system. This means that the only pathway of concern is the atmospheric pathway. However, it was illustrated in Section 11.3.2 that the release of dust particles into the atmosphere from the CPP stacks is minimal and limited to PM_{10}. Radon gas and dust particles larger than 10 micron is not released from the stacks. These is thus no contribution to the secondary pathways associated with the Commercial Agricultural Exposure Condition other than dust inhalation.

An estimate of the activity concentrations in the dust particles that will potentially be releases from the stacks were presented in Section 9.5. Figure 12-5 presents the resulting dust inhalation dose to adult members of the public induced by PM_{10} releases from the CPP stacks. The results confirm that the contribution of the CPP to the total effective dose under normal operating conditions is minimal and insignificant.

Table 12-2: Pathway specific contribution to the total effective dose using untreated water from the RWD for a Commercial Agricultural Exposure Condition.

Ingestion Dose in µSv.a^{-1}					
Pathway	**0 - 2 Years**	**2 - 7 Years**	**7 - 12 Years**	**12 – 17 Years**	**Adults**
Water	5.7E+02	4.6E+02	4.7E+02	6.8E+02	4.2E+02
Soil	2.6E-02	2.3E-02	2.4E-02	3.9E-02	2.2E-02
Leafy Vegetables	2.6E+01	2.0E+01	2.4E+01	4.4E+01	1.8E+01
Root Vegetables	2.4E+01	2.0E+01	2.5E+01	5.2E+01	1.8E+01
Fruit	2.4E+01	2.0E+01	2.1E+01	3.5E+01	1.9E+01
Cereal	2.3E+01	1.9E+01	1.9E+01	2.8E+01	1.8E+01
Meat (Beef)	2.8E+00	2.2E+00	2.4E+00	4.4E+00	1.8E+00
Meat (Mutton)	1.5E+01	1.2E+01	1.2E+01	1.8E+01	1.2E+01
Poultry	1.0E+01	7.9E+00	7.5E+00	1.0E+01	7.9E+00
Milk	1.3E+01	1.1E+01	1.1E+01	1.6E+01	1.1E+01
Eggs	4.3E+00	3.4E+00	3.3E+00	4.3E+00	3.4E+00
Total Ingestion Dose	**7.1E+02**	**5.8E+02**	**5.9E+02**	**9.0E+02**	**5.3E+02**

Table 12-3: Pathway specific contribution to the total effective dose using treated water from the AWTF for a Commercial Agricultural Exposure Condition.

Ingestion Dose in µSv.a^{-1}					
Pathway	**0 - 2 Years**	**2 - 7 Years**	**7 - 12 Years**	**12 – 17 Years**	**Adults**
Water	3.9E+01	3.2E+01	3.2E+01	4.7E+01	2.9E+01
Soil	1.8E-03	1.6E-03	1.7E-03	2.7E-03	1.6E-03
Leafy Vegetables	1.8E+00	1.4E+00	1.6E+00	3.0E+00	1.2E+00
Root Vegetables	1.7E+00	1.4E+00	1.7E+00	3.6E+00	1.2E+00
Fruit	1.7E+00	1.4E+00	1.5E+00	2.4E+00	1.3E+00
Cereal	1.6E+00	1.3E+00	1.3E+00	1.9E+00	1.2E+00
Meat (Beef)	1.9E-01	1.5E-01	1.7E-01	3.0E-01	1.2E-01
Meat (Mutton)	1.0E+00	8.2E-01	8.3E-01	1.2E+00	8.5E-01
Poultry	6.9E-01	5.4E-01	5.2E-01	6.8E-01	5.4E-01
Milk	9.2E-01	7.5E-01	7.7E-01	1.1E+00	7.8E-01

Eggs	3.0E-01	2.3E-01	2.2E-01	3.0E-01	2.4E-01
Total Ingestion Dose	**4.9E+01**	**4.0E+01**	**4.1E+01**	**6.1E+01**	**3.6E+01**

12.4.3 Radiological Impact associated with the RTSF

The two pathways of concern for the RTSF is the groundwater and atmospheric pathways. During normal operations, excess water from the RTSF will be channelled to the RWD for reuse or treatment in the AWTF (See Section 12.4.1).

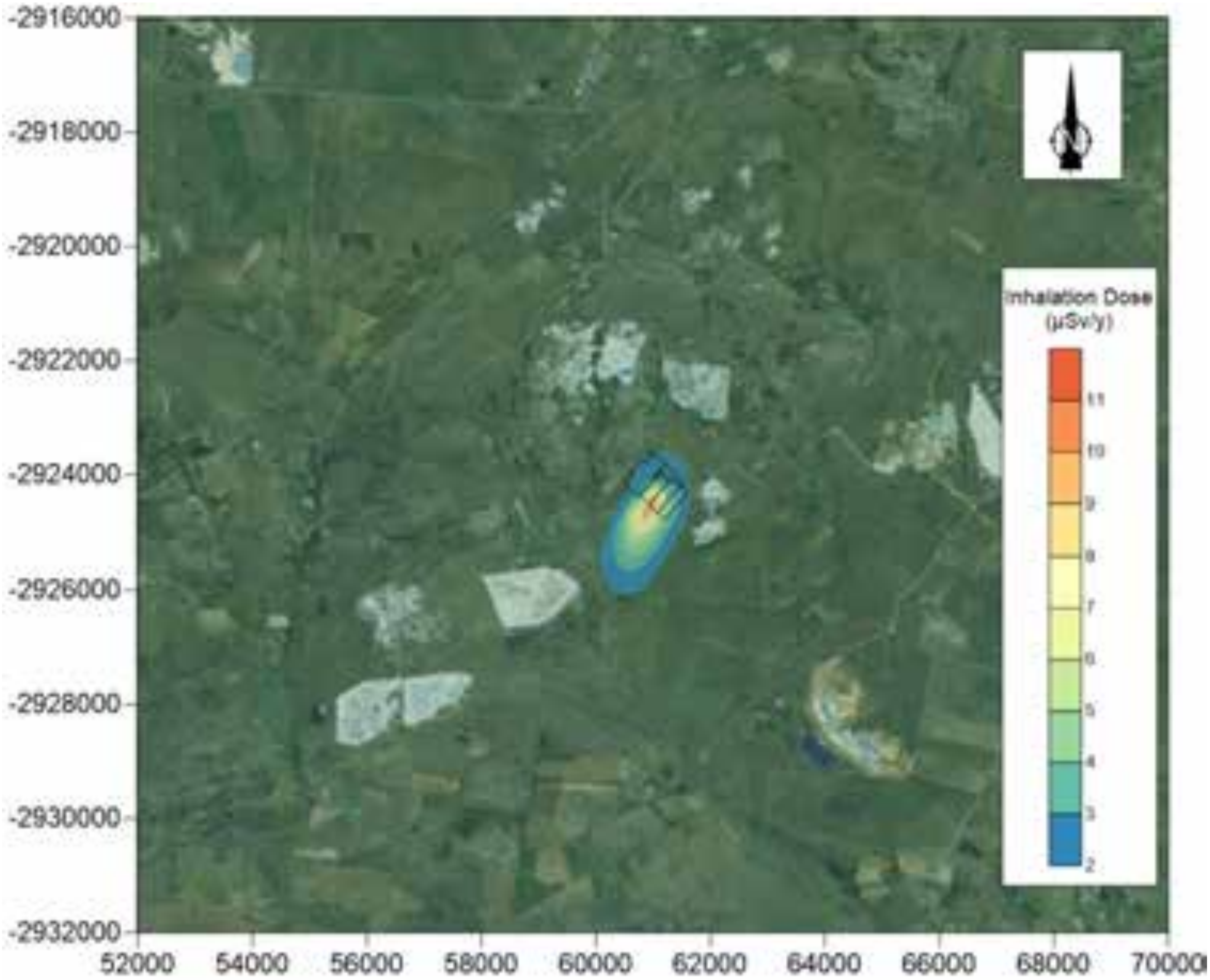

Figure 12-5: The resulting dust inhalation dose to adult members of the public induced by PM_{10} releases from the CPP stacks.

12.4.3.1 Groundwater Pathway

Due to the importance of groundwater as a source of water, especially in the agricultural section, one can assume that the groundwater pathway is and always will be a sensitive pathway to consider. The impact of the RTSF on the groundwater pathway from an inorganic perspective were addressed extensively in Digby Wells Environmental (2015g), including the potential impact of remedial measures to contain any potential contaminant plume.

Section 12.1 briefly highlighted the fact that the leaching and subsequent migration of any naturally occurring radionuclides from a TSF is an inherently slow process, mainly due to geochemical processes that results in the retardation of radionuclides. For this reason, a radionuclide contaminant plume is seldom *observed* near a TSF. However, site specific conditions may vary and some isotopes may migrate over short distances.

To evaluate the radiological impact of the RTSF on the groundwater pathway, a system level modelling approach using Ecolego were followed, using parameter values extracted from the *Process Level Model* presented in Digby Wells Environmental (2015g).

Figure 12-6 presents the *System Level Model* implementation in Ecolego to evaluate the contribution of the groundwater pathway. The *Distributed Source Term to Groundwater* compartment represents the RTSF containing the residue material that serves as a groundwater pathway source. The *Unsaturated Zone Transport* compartment represents the unsaturated zone between the source and the water table (aquifer). The *Aquifer Mixing Zone* compartment represents the aquifer area beneath the source to account for mixing of infiltrating contaminated water with uncontaminated water flowing down gradient. Two *Aquifer Transport* compartments are included to account for potentially different aquifer zones and to facilitate the abstraction of modelling results at different distances. These compartments represent the migration of radionuclides in the saturated zone. Finally, the *Well* compartment represents a groundwater abstraction point.

Figure 12-6: Screen capture of the model implementation in Ecolego used to evaluate the contribution of the groundwater pathway from the RTSF.

To evaluate the radiological impact of the RTSF, the following were assumed for the purpose of the modelling (as abstracted from Digby Wells Environmental (2015g)):

- The unsaturated zone is defined by the water level below surface, which under pre-operational conditions is in the order of 7 to 10 m. During operations, the unsaturated zone will reduce to zero and will last for 100 years after closure (post-operational), after which the pre-operational water level will be restored.
- Consistent with the process level model, the aquifer thickness (weathered zone) beneath the RTSF is assumed to be 30 m.

- The hydraulic gradient in the direction of groundwater flow is 0.0051, which translate into a Darcy velocity of 0.0011 $m.d^{-1}$ (or 0.385 $m.y^{-1}$) for a hydraulic conductivity of 0.207 $m.d^{-1}$ in the weathered aquifer.
- Assuming an effective porosity of 0.03 for the weathered aquifer, the groundwater flow velocity in the direction of groundwater flow equates to 0.0352 $m.d^{-1}$ or 12.85 $m.y^{-1}$.
- The maximum flow path in the direction of groundwater flow (towards the surface water bodies) is assumed to be 7100 m, which means that an *advective* contaminant plume would reach these receptor points in about 553 years.
- The hydraulic gradient in the direction of the Leeuspruit (perpendicular to the general groundwater flow direction) is 0.001, which translate into a Darcy velocity of 0.000207 $m.d^{-1}$ (or 0.0756 $m.y^{-1}$) for a hydraulic conductivity of 0.207 $m.d^{-1}$ in the weathered aquifer.
- Assuming an effective porosity of 0.03 for the weathered aquifer, the groundwater flow velocity in the direction of the Leeuspruit equates to 0.0069 $m.d^{-1}$ or 2.52 $m.y^{-1}$.
- The maximum flow path towards the Leeuspruit is assumed to be 350 m, which means that an *advective* contaminant plume would reach these receptor points in about 139 years.

Assuming a low level of retardation in the RTSF (source), unsaturated zone and aquifer (sand values in Table 12-4), and the parameter values listed in Table 12-5, the resulting concentration in groundwater and associated water ingestion dose can be calculated. The first set of results are presented in Figure 12-7 and Figure 12-8 for a downstream borehole located 300 m in the direction of flow. For this purpose, the Sand K_d-values in Table 12-4 (conservative), and the activity concentrations in the RTSF tailings listed in Table 9-11 were used as additional input values to those listed in Table 12-5. Note that as a conservative assumption, it was assumed that 50% of the uranium is extracted from the tailings in Table 9-14.

Using a similar approach and the parameter values listed in Table 12-6, the resulting concentration in groundwater and associated water ingestion dose at a borehole located 300 m in the direction of the Leeuspruit was calculated. However, due to much lower Darcy velocity due to a lower gradient (almost an order of magnitude lower), the contaminant plume does not reach the borehole in 1 million years.

Table 12-4: Distribution coefficients for the isotopes of concern for different soil types compiled from various sources.

Element	Resrad (Yu *et al.*, 1993)					NNR RG-002
	Sand	Loam	Clay	Organic	Default	All soils
	K_d-values ($m^3.kg^{-1}$)					
U	0.035	0.015	1.60	0.41	0.05	0.20
Th	3.20	3.30	5.80	89	60	1.9

Ra	0.50	36	9.10	2.40	0.07	2.50
Pb	0.27	16	0.55	22.00	0.10	2.00
Po	0.15	0.40	3.00	7.30	0.010	0.21
Pa	0.55	1.80	2.70	6.60	0.05	2.00
Ac	0.45	1.50	2.40	5.40	0.02	1.70

Table 12-5: Summary of the parameter values assumed for the source (RTSF), unsaturated zone, and saturated zone to quantify the contribution of the groundwater pathway at a borehole 7000 m in the direction of flow.

Unit	Parameter	Unit	Value
Source (TSF)	Area of the TSF	m^2	1.599E+07
	Length and width of the TSF	m	5330
	Thickness of the TSF	m	50
	Dry Bulk Density of Tailings	$kg.m^{-3}$	1,800
	Infiltration Rate into TSF (3% of MAP of 693 mm)	$m.y^{-1}$	0.0208
	Volumetric Moisture Content	-	0.3
Unsaturated Zone	Dry Bulk Density	$kg.m^{-3}$	2,000
	Infiltration Rate Through Unsaturated Zone	$m.a^{-1}$	0.0208
	Volumetric Moisture Content	-	0.3
	Thickness of Unsaturated Zone	m	7
Aquifer	Aquifer Thickness	m	30
	Distance to Borehole (flow tube)	m	300
	Darcy Velocity in Direction of Flow	$m.y^{-1}$	0.385
	Dry Bulk Density	$kg.m^{-3}$	2,000
	Aquifer Porosity	-	3%

The results confirmed the notion that the groundwater travel times for radionuclides due to retardation processes is a very slow process. Whereas the advective travel time to a point 7000 m downstream is in the of 550 years, peak concentrations will not reach this point in 1 million years. Higher and probably more realistic Kd-values (higher adsorption along the flow path) will retard the contaminant plume even further.

It is also worth noting that the mitigation measure evaluated in Digby Wells Environmental (2015g) will not have a noticeable effect on the groundwater pathway due to the timescales of concern. These measures include the installation of a blast curtain, and/or the installation of a liner system.

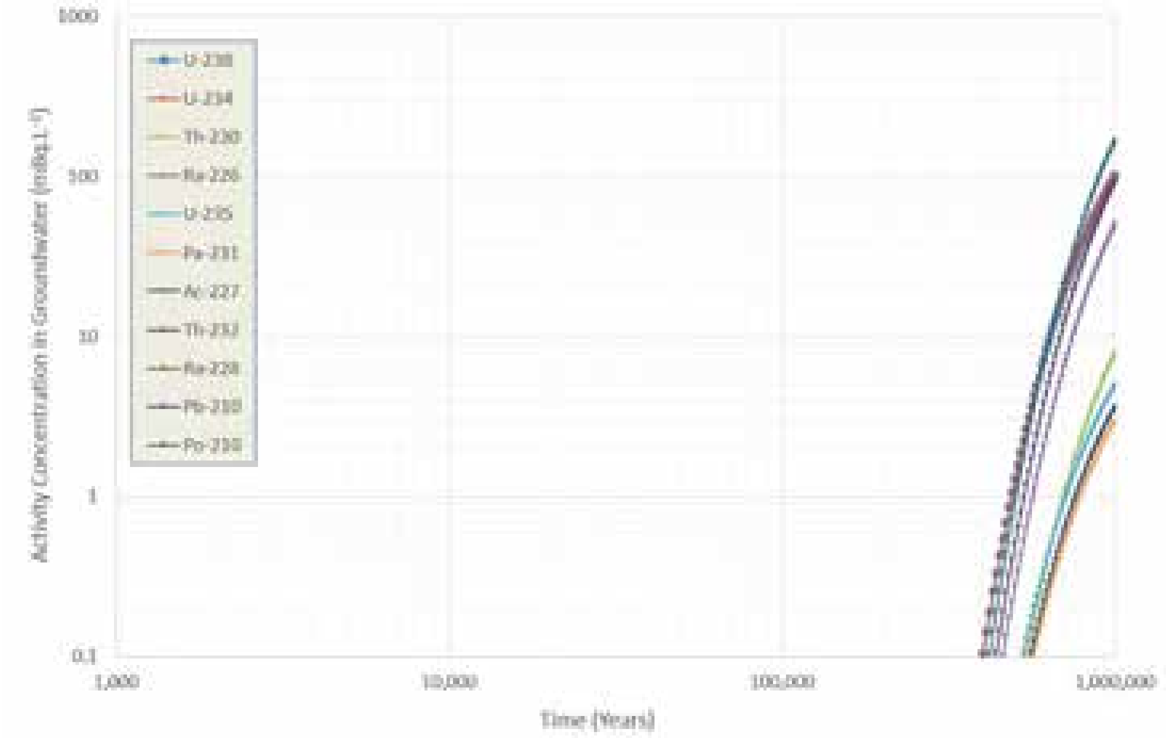

Figure 12-7: The simulated activity concentration in groundwater abstracted from a borehole 300 m from the RTSF in the direction of flow, using the parameter values listed in Table 12-5.

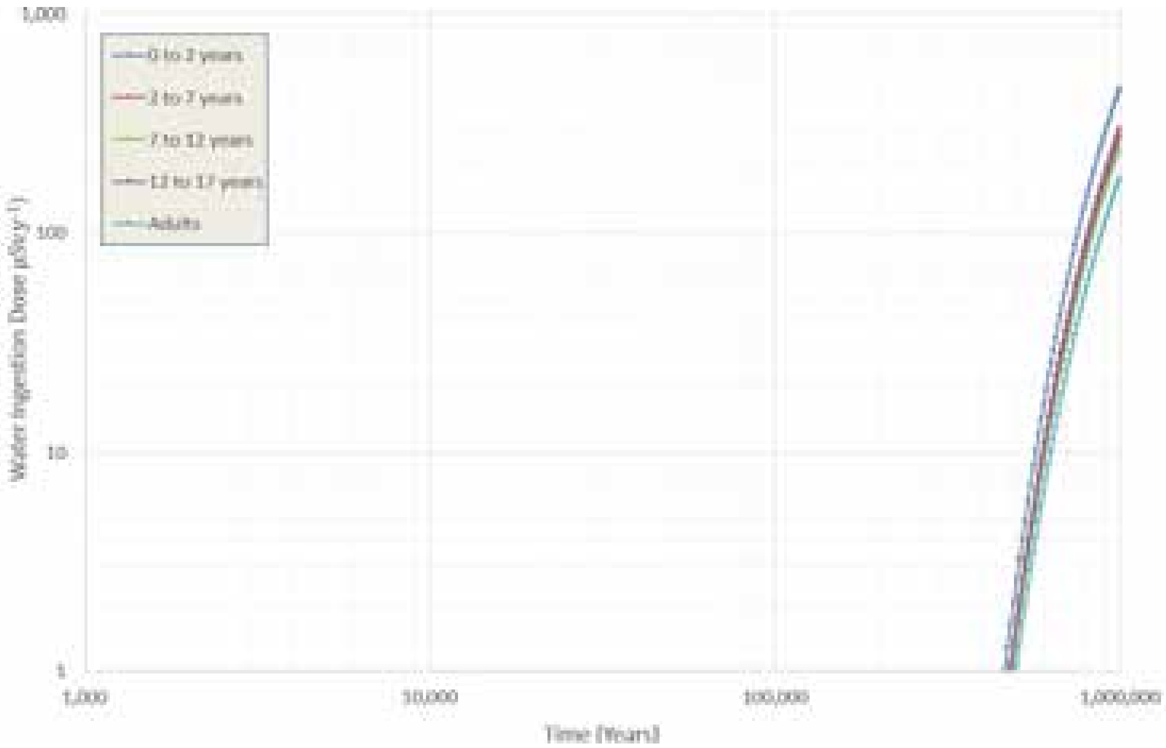

Figure 12-8: The simulated water ingestion dose to the different age groups, using the parameter values listed in Table 12-5 and the activity concentrations in Figure 12-7.

Table 12-6: Summary of the parameter values assumed for the source (RTSF), unsaturated zone, and saturated zone to quantify the contribution of the groundwater pathway at a borehole 300 m in the direction of the Leeuspruit.

Unit	Parameter	Unit	Value
Source (TSF)	Area of the TSF	m^2	1.599E+07
	Length and width of the TSF	m	5330
	Thickness of the TSF	m	50
	Dry Bulk Density of Tailings	$kg.m^{-3}$	1,800
	Infiltration Rate into TSF (3% of MAP of 693 mm)	$m.a^{-1}$	0.0208
	Volumetric Moisture Content	-	0.3
Unsaturated Zone	Dry Bulk Density	$kg.m^{-3}$	2,000
	Infiltration Rate Through Unsaturated Zone	$m.a^{-1}$	0.0208
	Volumetric Moisture Content	-	0.3
	Thickness of Unsaturated Zone	m	7
Aquifer	Aquifer Thickness	m	30
	Distance to Borehole (flow tube)	m	300
	Darcy Velocity in Direction of Flow	$m.a^{-1}$	0.0756
	Dry Bulk Density	$kg.m^{-3}$	2,000
	Aquifer Porosity	-	3%

12.4.3.2 Atmospheric Pathway

One of the major differences between possible contributions from the groundwater and the atmospheric pathways are the timescales of concern. The possible contribution from the groundwater pathway was illustrated in Section 12.4.3.1 to be a very slow process, and may manifest itself only in hundreds of thousands of years post-closure. The possible contribution from the atmospheric pathway, on the other hand, is from commissioning, and will continue during the post-closure period.

To evaluate the contribution of the atmospheric pathway, the contribution from the airborne PM_{10}, TSP and radon concentrations presented in Section 10.2.1 were considered for the Commercial Agricultural Exposure Condition defined in Section 10.5.3. Assuming a deposition period of a 1000 years, Figure 12-9 presents the resulting total effective dose to adult members of the public induced by the airborne PM_{10} and TSP concentrations, while Figure 12-10 presents the contribution from the airborne radon concentration derived in Parc Scientific (2015) to the radon inhalation dose. The radon inhalation dose were calculated using a dose conversion factor of 25.74 µSv per $Bq.m^{-3}$, and a radon exhalation rate of 0.65 $Bq.m^{-2}.s^{-1}$ based on a Ra-226 content of 490 $Bq.kg^{-1}$ (see Table 9-11).

From Figure 12-9 and Figure 12-10 it is clear that the contribution from PM_{10} and TSP is relatively low and decrease within a short distance away from the RTSF in a southwesterly directions, to below 100 $µSv.y^{-1}$. The contribution from radon inhalation, on the other hand, is much more significant, with the main area of impact towards the northeast. In the vicinity of the Leeuspruit the radon inhalation dose is still in the order of 200 $µSv.y^{-1}$, while in the vicinity of the Gold Fields Doornpoort TSF the radon inhalation dose reduces to less than 80 μSv.y^{-1}.

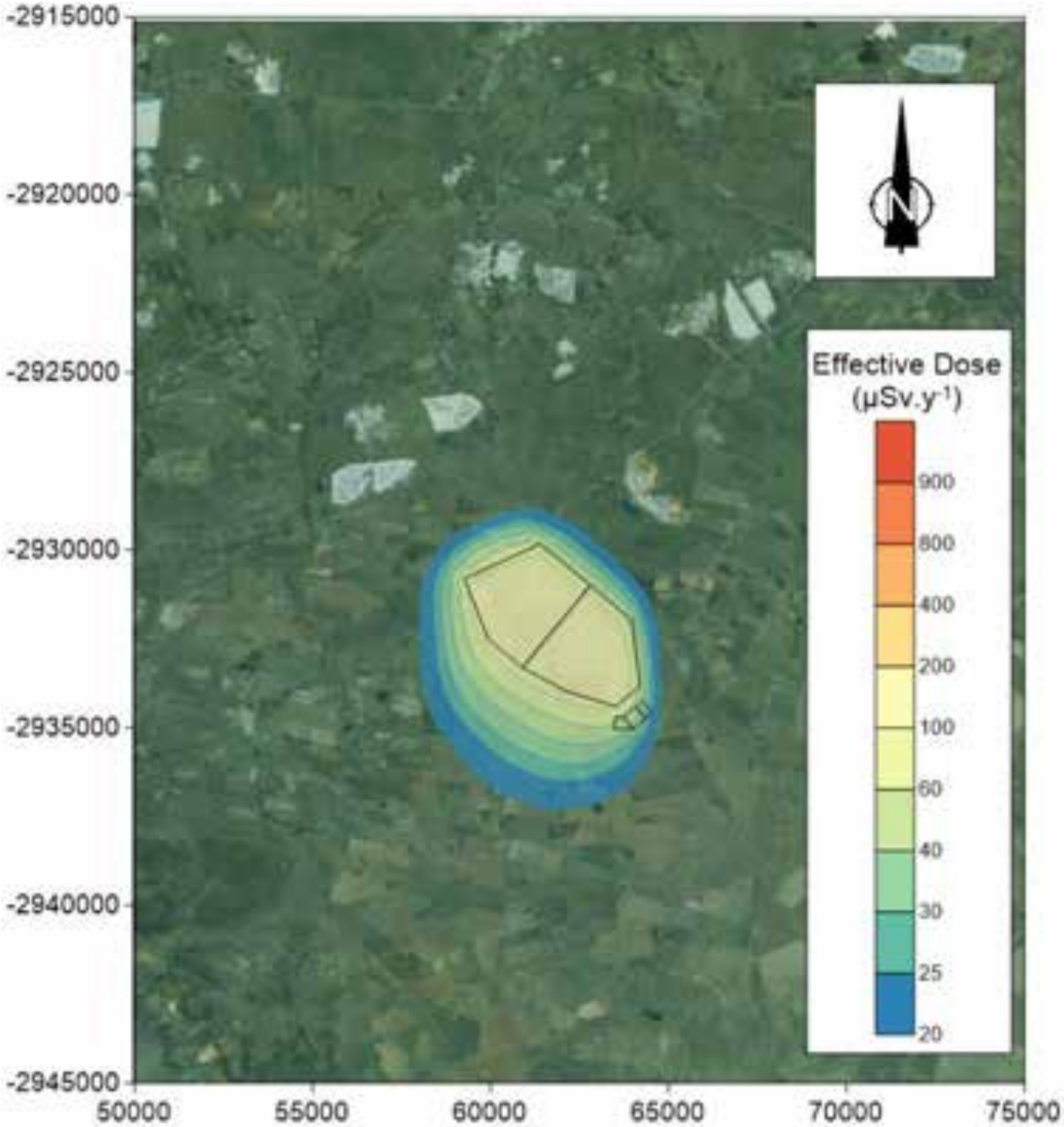

Figure 12-9: Effective dose to adult members of the public induced by the airborne PM10 and TSP released from the RTSF, for the Commercial Agricultural Exposure Condition (assuming a 1000 years deposition period).

Note that these doses are conservative, and assume living permanently in the area with standards exposure periods indoors and outdoors. The radon exhalation rate of 0.64 Bq.m^{-2}.s^{-1} is also assuming no covering layer as mitigation measure during revegetation. A covering layer of 0.25 m, may reduce the radon exhalation rate to 0.41 Bq.m^{-2}.s^{-1}, and thus the radon inhalation dose accordingly. Figure 12-11 presents the resulting radon inhalation dose.

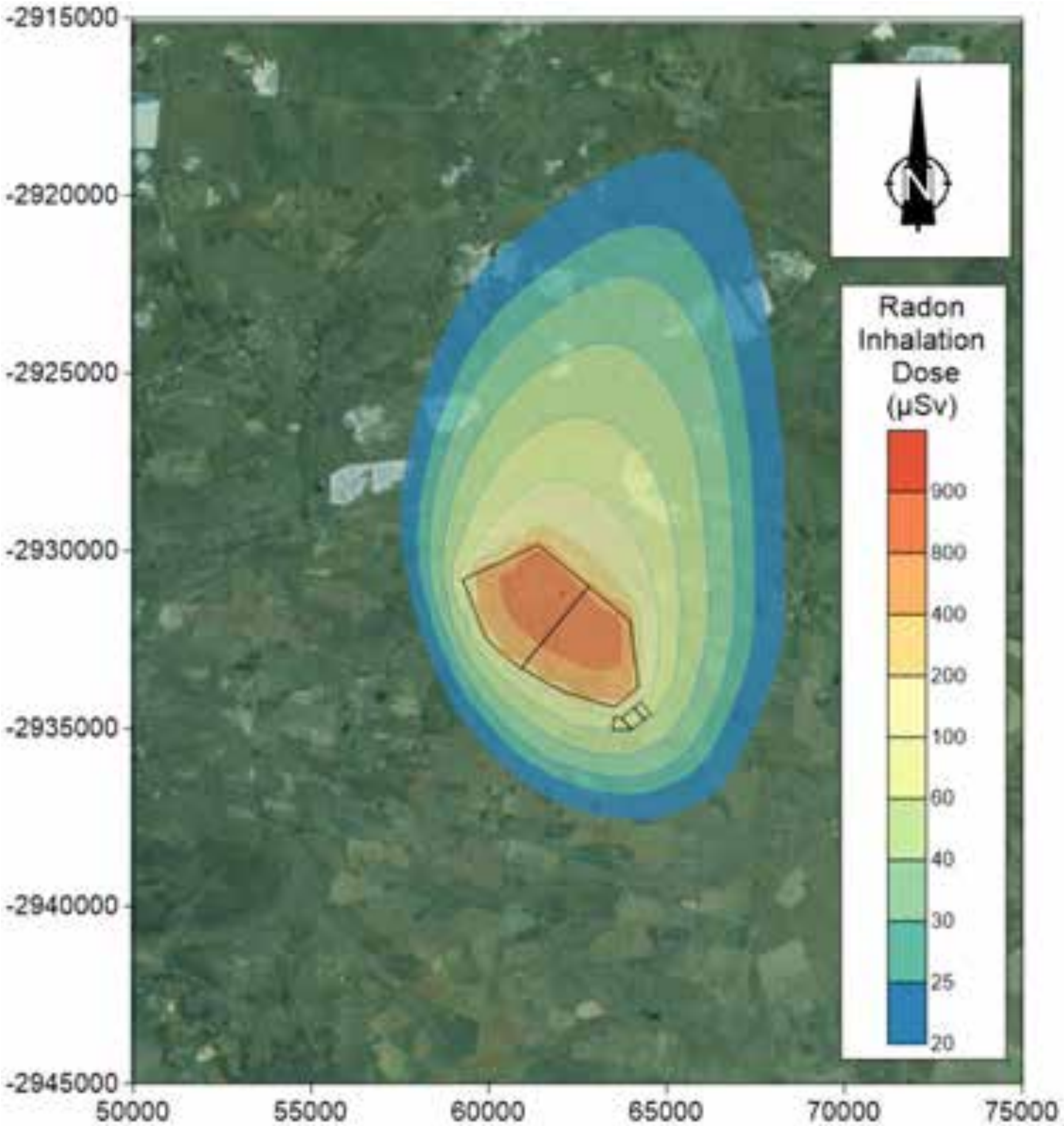

Figure 12-10: Radon inhalation dose to adult members of the public induced by the airborne radon concentration released from the RTSF, for the Commercial Agricultural Exposure Condition.

12.5 Driefontein Operations

The WRTRP activities associated with the Driefontein Operations that are of relevance from a radiological impact assessment perspective (see Section 10.1) are the retreatment of

Driefontein No. 3 and Driefontein No. 5 TSFs. After retreatment, the site will be rehabilitated and cleaned to levels suitable for future land use conditions.

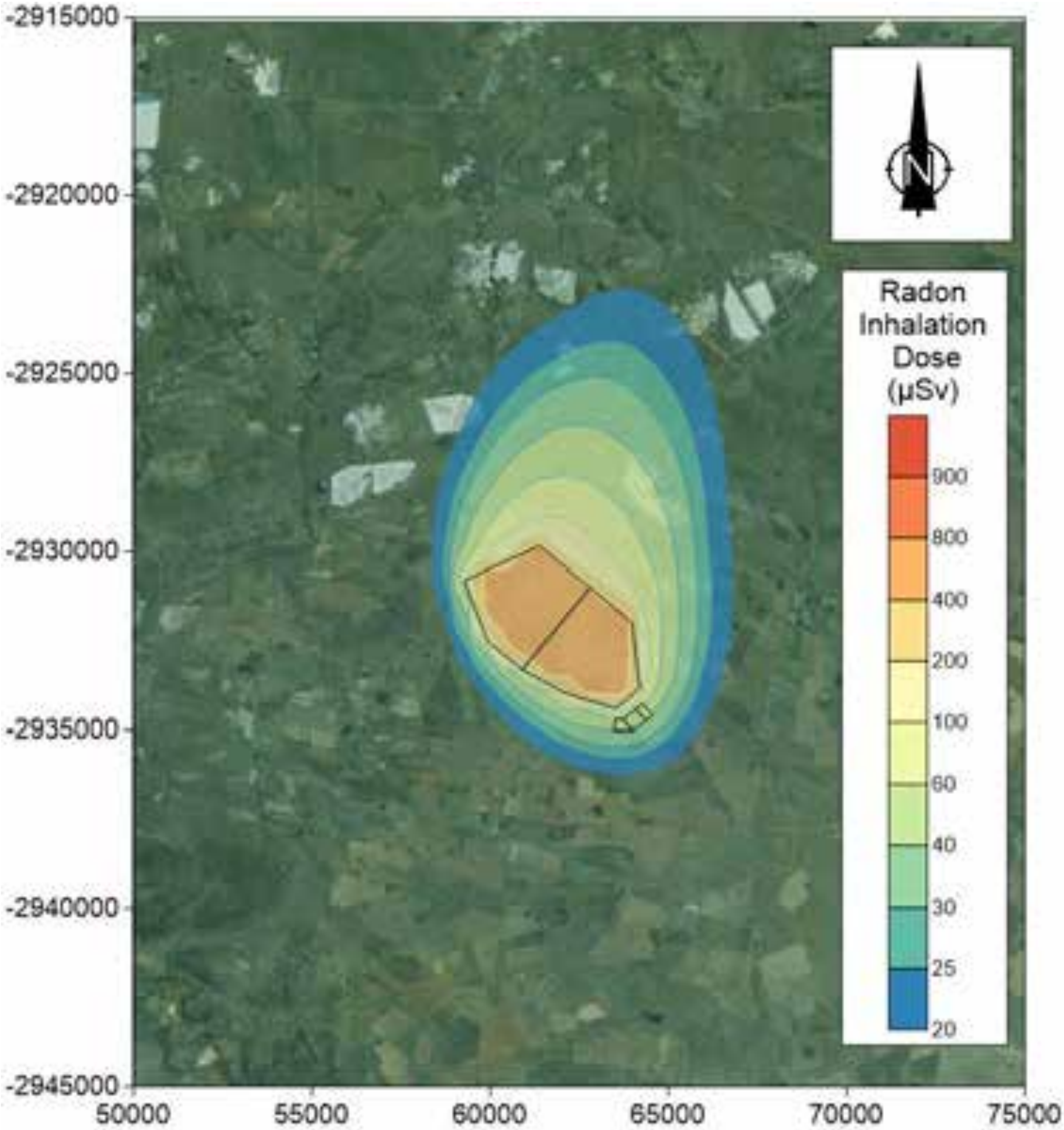

Figure 12-11: Radon inhalation dose to adult members of the public induced by the airborne radon concentration released from the RTSF, for the Commercial Agricultural Exposure Condition (assuming a cover layer of 0.25 m).

12.5.1 Current radiological impact

Under current operational conditions and over the timescales of concern, the major contribution to a total effective dose from the reclamation of the two TSFs for a Commercial Agricultural Exposure Condition, is through the atmospheric pathway. PM_{10} and radon gas released from the TSFs contribute to a gas and radon inhalation doses, while TSP released from the TSFs and deposited into the environment contributes to secondary exposure pathways included in the Commercial Agricultural Exposure Condition.

One can assume that the total effective dose contribution from these two TSFs for the current conditions is below the NNR compliance criteria for radiation protection for members of the public. Consistent with the contribution from the atmospheric pathway, the current radiological impact from the TSFs is highest very close to the TSFs, but decrease significantly with distance away from the TSF. The direction and extent of the radiological impact is controlled by the local prevailing meteorological conditions used in the atmospheric dispersion modelling.

12.5.2 Radiological impact during retreatment

The retreatment of the Driefontein No. 3 and Driefontein No. 5 TSFs is a wet process using hydraulic sluicing. This means that any contribution from the atmospheric pathway for that section of the TSF will be eliminated during reclamation. Effectively, the source term release rate of dust and radon is reduced, which means that the potential radiological impact through the atmospheric pathway is reduced accordingly. One can therefore expect the radiological impact also to be less during the retreatment process.

The contribution through the groundwater pathway is not expected to change significantly, if at all. The use of hydraulic sluicing during retreatment means that additional water is present that might increase the source term release rate to the underlying aquifer. However, this will not influence the migration of radionuclides in the aquifer itself, which was illustrated to be an inherently slow process. Storm water management practices will be applied during the retreatment process, which means that excess water will be channelled back into the system. Water will not be released from the site. This means that the potential radiological impact during retreatment will be similar to those under current (baseline) conditions.

12.5.3 Future radiological impact

The assumption is that once the footprints of the Driefontein No. 3 and Driefontein No. 5 TSFs has been retreated, then the site will be rehabilitated and cleaned to levels suitable for the anticipated future land use condition. This means that all the tailings material that contains naturally occurring radionuclides will be removed, and effectively remove the source of radiation exposure. The implication is that the contribution of these two TSFs will be eliminated, resulting in a significant positive radiological impact to members of the public in the vicinity of the Driefontein No. 3 and Driefontein No. 5 TSFs.

13 Sensitivity analysis and no-go areas

Potential exposure to ionizing radiation induced by mining and mineral processing operations in itself is a sensitive issues and, therefore, has to be treated and managed with the necessary sensitivity within the framework provided by the nuclear authorisation process administrated by the NNR. The only criteria available in South Africa for this purpose is the standards published in Regulation 388 in terms of the public dose limited and associated dose constraint (see Section 6.4.1).

It was mentioned in Section 10.5.6 that the Commercial Agricultural Exposure Condition does not represent the only exposure condition for the area or the WRTRP. Other exposure conditions might have been equally applicable, but it was argued that the conditions assumed for the Commercial Agricultural Exposure Condition is very conservative. Any other exposure condition would result in lower radiation doses.

Furthermore, the parameter values used for the purpose of the assessment were also on the conservative side and consistent for the NNR guidelines provided in RG-002 (NNR, 2013b). More conservative or more realistic parameter values can be assessed, but it will not necessarily change the outcome of the impact assessment.

Most of the facilities and activities associated with the WRTRP in the four Mining Right areas and their respective CoRs are located and will be operated within access controlled areas, which means that members of the public will not have uncontrolled access to these facilities. These include in particular the following in varying degrees:

- The CPP and Ezulwini processing plant areas;
- The Advance Water Treatment Facility;
- The block thickeners and BWSFs; and
- The operating TSFs, associated water management facilities, and the reclamation areas.

These areas and the control measures that applies will be defined in the respective Physical Security Procedures to be submitted and approved by the NNR as part of the RMP for each CoR (see Section 17). The physical security measures are further supplemented with a public RPP that defines measures to ensure that members of the public are protected from exposure to ionizing radiation.

However, due to the physical size of the TSFs, and in particular the RTSF, members of the public may have access to these facilities. No access cannot be guaranteed and people may dwell into these areas. Radiation exposure close to the facility will be the highest, which will decrease significantly with distance away from the facility. Measures will be implemented to make members of the public aware of radiations risks (e.g. fencing and display of radiation risks signage), while physical surveillance measures as part of the RMP will ensure that trespassing is minimised. Land use restriction (e.g. commercial farming) in close proximity of the TSF (e.g. within a few hundred metres) should be applied. Figure 13-1 shows the 200 μSv boundary from radon inhalation for mitigated and unmitigated conditions. This will ensure compliance with the dose constraint of 250 $\mu Sv.y^{-1}$ (assuming a further 50 $\mu Sv.y^{-1}$ contribution from the other exposure routes). Note that the impacted area from the other exposure routes is in the opposite direction towards the southwest.

Even more difficult to control from a public access perspective, is the water and tailings pipelines. Some of these pipelines between facilities run through open veld, which makes it basically impossible to control in terms of public access. However, the radiation risk associated with the pipelines under normal operating conditions is minimal.

The contribution from the CPP to a total effective dose was illustrated to be minimal, and consequently it is not necessary to define no go areas for this facility, other that would be provided through physical security.

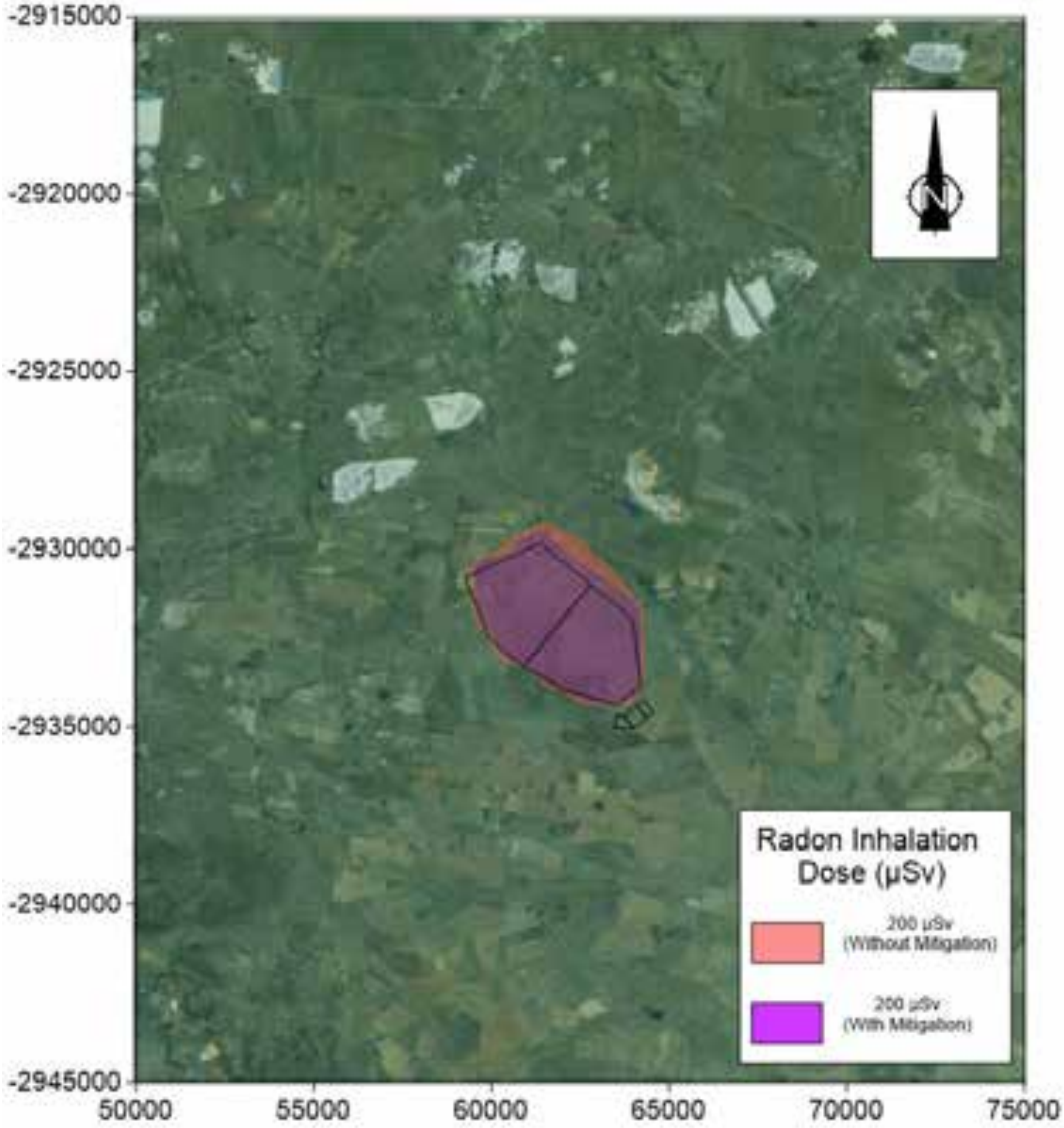

Figure 13-1: The 200 µSv boundaries for radon inhalation for mitigated and unmitigated conditions.

14 Impact Assessment

14.1 Methodology and criteria

Based on South African legislation and guidelines, the following criteria will be taken into account when examining potentially significant impacts:

- Nature of impacts (induced/direct/indirect, positive/negative);
- Duration (short/medium/long-term, permanent(irreversible) / temporary (reversible), frequent/seldom);
- Extent (geographical area, size of affected population/habitat/species);
- Intensity (minimal, severe, replaceable/irreplaceable);
- Probability (high/medium/low probability); and
- Mitigation (as per mitigation hierarchy: avoid, mitigate or offset significant adverse impacts).

The significance rating process follows the established impact/risk assessment formula:

SIGNIFICANCE = CONSEQUENCE[2] x PROBABILITY[3] x NATURE[4]

The matrix (see Table 14-2) calculates the rating out of 147 points, whereby intensity, extent, duration and probability are each rated out of seven as indicated in Table 14-1. The weight assigned to the parameters is then multiplied by +1 for positive and -1 for negative impacts.

Impacts are rated prior to mitigation, and again after consideration of the mitigation has been applied; post-mitigation is referred to as the residual impact. The significance of an impact is determined and categorised into one of seven categories (The descriptions of the significance ratings are presented in Table 14-3). It is important to note that the pre-mitigation rating takes into consideration the activity as proposed, (i.e., there may already be some mitigation included in the engineering design). If the specialist determines the potential impact is still too high, additional mitigation measures are proposed.

The primary management objective from a public radiation protection perspective for all three Mining Right areas is to comply with national legislation as defined in Regulation 388 (April 2006). The total effective dose limit to members of the public from all contributing sources is 1 mSv per annum, while the dose constraint of 0.25 mSv per annum is applied as part of the optimisation of radiation protection. A secondary management objective is to apply the ALARA principle, which assumes that the total effective dose is kept As Low As Reasonable Achievable, economic and social factors taken into consideration.

[2] Consequence = Intensity + Extent + Duration

[3] Probability = Likelihood of and impact occurring

[4] Nature = Positive (+1) or Negative (-1) impact

Table 14-1: Impact Assessment Parameter Ratings

Rating	Intensity		Extent	Duration/reversibility	Probability
	Negative impacts	Positive impacts			
7	Irreplaceable loss or damage to biological or physical resources or highly sensitive environments. Irreplaceable damage to highly sensitive cultural/social resources.	Noticeable, on-going natural and / or social benefits which have improved the overall conditions of the baseline.	International The effect will occur across international borders.	Permanent: The impact is irreversible, even with management, and will remain after the life of the project.	Definite: There are sound scientific reasons to expect that the impact will definitely occur. >80% probability.
6	Irreplaceable loss or damage to biological or physical resources or moderate to highly sensitive environments. Irreplaceable damage to cultural/social resources of moderate to highly sensitivity.	Great improvement to the overall conditions of a large percentage of the baseline.	National Will affect the entire country.	Beyond project life: The impact will remain for some time after the life of the project and is potentially irreversible even with management.	Almost certain / Highly probable: It is most likely that the impact will occur. <80% probability.

Rating	Intensity		Extent	Duration/reversibility	Probability
	Negative impacts	Positive impacts			
5	Serious loss and/or damage to physical or biological resources or highly sensitive environments, limiting ecosystem function. Very serious widespread social impacts. Irreparable damage to highly valued items.	On-going and widespread benefits to local communities and natural features of the landscape.	Province/ Region Will affect the entire province or region.	Project Life (>15 years): The impact will cease after the operational life span of the project and can be reversed with sufficient management.	Likely: The impact may occur. <65% probability.
4	Serious loss and/or damage to physical or biological resources or moderately sensitive environments, limiting ecosystem function. On-going serious social issues. Significant damage to structures / items of cultural significance.	Average to intense natural and / or social benefits to some elements of the baseline.	Municipal Area Will affect the whole municipal area.	Long term: 6-15 years and impact can be reversed with management.	Probable: Has occurred here or elsewhere and could therefore occur. <50% probability.

Rating	Intensity		Extent	Duration/reversibility	Probability
	Negative impacts	Positive impacts			
3	Moderate loss and/or damage to biological or physical resources of low to moderately sensitive environments and, limiting ecosystem function. On-going social issues. Damage to items of cultural significance.	Average, on-going positive benefits, not widespread but felt by some elements of the baseline.	Local Local extending only as far as the development site area.	Medium term: 1-5 years and impact can be reversed with minimal management.	Unlikely: Has not happened yet but could happen once in the lifetime of the project, therefore there is a possibility that the impact will occur. <25% probability.
2	Minor loss and/or effects to biological or physical resources or low sensitive environments, not affecting ecosystem functioning. Minor medium-term social impacts on local population. Mostly repairable. Cultural functions and processes not affected.	Low positive impacts experience by a small percentage of the baseline.	Limited Limited to the site and its immediate surroundings.	Short term: Less than 1 year and is reversible.	Rare / improbable: Conceivable, but only in extreme circumstances. The possibility of the impact materialising is very low as a result of design, historic experience or implementation of adequate mitigation measures. <10% probability.

Rating	Intensity		Extent	Duration/reversibility	Probability
	Negative impacts	**Positive impacts**			
1	Minimal to no loss and/or effect to biological or physical resources, not affecting ecosystem functioning. Minimal social impacts, low-level repairable damage to commonplace structures.	Some low-level natural and / or social benefits felt by a very small percentage of the baseline.	<u>Very limited/Isolated</u> Limited to specific isolated parts of the site.	Immediate: Less than 1 month and is completely reversible without management.	Highly unlikely / None: Expected never to happen. <1% probability.

Table 14-2: Probability/Consequence Matrix

Probability	Significance																																					
7	-147	-140	-133	-126	-119	-112	-105	-98	-91	-84	-77	-70	-63	-56	-49	-42	-35	-28	-21	21	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147
6	-126	-120	-114	-108	-102	-96	-90	-84	-78	-72	-66	-60	-54	-48	-42	-36	-30	-24	-18	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
5	-105	-100	-95	-90	-85	-80	-75	-70	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20	-15	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
4	-84	-80	-76	-72	-68	-64	-60	-56	-52	-48	-44	-40	-36	-32	-28	-24	-20	-16	-12	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84
3	-63	-60	-57	-54	-51	-48	-45	-42	-39	-36	-33	-30	-27	-24	-21	-18	-15	-12	-9	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63
2	-42	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
1	-21	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Consequence	-21	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Table 14-3: Significance Rating Description[5]

Score	Description	Rating
109 to 147	A very beneficial impact that may be sufficient by itself to justify implementation of the project. The impact may result in permanent positive change	Major (positive) (+)
73 to 108	A beneficial impact which may help to justify the implementation of the project. These impacts would be considered by society as constituting a major and usually a long-term positive change to the (natural and / or social) environment	Moderate (positive) (+)
36 to 72	A positive impact. These impacts will usually result in positive medium to long-term effect on the natural and / or social environment	Minor (positive) (+)
3 to 35	A small positive impact. The impact will result in medium to short term effects on the natural and / or social environment	Negligible (positive) (+)
-3 to -35	An acceptable negative impact for which mitigation is desirable. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in negative medium to short term effects on the natural and / or social environment	Low (negative) (-)
-36 to -72	A minor negative impact requires mitigation. The impact is insufficient by itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in negative medium to long-term effect on the natural and / or social environment	Medium-low (negative) (-)
-73 to -108	A moderate negative impact may prevent the implementation of the project. These impacts would be considered as constituting a major and usually a long-term change to the (natural and / or social) environment and result in severe changes.	Medium-high (negative) (-)
-109 to -147	A major negative impact may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts are immitigable and usually result in very severe effects. The impacts are likely to be irreversible and/or irreplaceable.	High (negative) (-)

[5] It is generally sufficient only to monitor impacts that are rated as negligible or minor

14.2 Kloof Mining Right Area Impact Assessment

The main WRPRP activities to consider from a radiological public impact perspective for the Kloof Mining Right area, are the abstraction of water from K10 shaft, surface infrastructure for the pipelines and associated booster pump stations, the CPP, as well as the RTSF and its associated components. The latter include the TSF itself, the RWD, and the associated AWTF.

14.2.1 Construction Phase

No material containing naturally occurring radionuclides are used or handled during the construction phase, and as a result there is no radiological impact to members of the public associated with the Kloof Mining Right area during this phase.

14.2.2 Operational Phase

Project activities associated with the Kloof Mining Right area that were considered as potential sources of public radiation exposure for the operational phase, are:

- The CPP and the extraction of gold, uranium and sulphur from tailings material;
- The RTSF and the associated deposition of reprocessed tailings material; and
- The AWTF and the subsequent release of purified water to the Leeuspruit.

Under normal operating conditions, the surface infrastructure for the pipelines and the booster pump stations are not considered as sources of radiation exposure to members of the public, while the physical abstraction of water from K10 shaft was screened out as a potential source of radiation exposure. The RWD at the RTSF consists of a series of compartments, and are designed in such a manner that releases to the environment is very unlikely. Not only will it comply with the requirements of the GN 704 regulations, the design include a geocomposite liner consisting of a geomembrane underlain by a 300 mm thick layer of clayey material. A seepage collection system will also be provided to intercept and identify any leakage. Furthermore, it was illustrated migration in the underlying aquifer is extremely slow in case leakage to the underlying does occur. No radiological impact is therefore expected from the RWD under normal operating conditions during the operational phase.

The CPP is located in a physical secured area, which means the direct exposure to members of the public is not possible. However, the CPP serve as a potential source of radiation exposure to members of the public, since dust particles (PM_{10}) containing naturally occurring radionuclides are released from the stacks into the atmosphere. These dust particles are inhaled, resulting in a radiological impact. The inhalation doses are low, resulting in a minimal impact, with a very limited area of impact. The impact will occur for as long as the plant is operational, and in all likelihood for the duration of the WRTRP. However, it is improbable that the impact will be above the compliance criteria. The resulting radiological impact rating presented in Table 14-4 suggests a **Low (negative) impact**. No mitigation measures are required to reduce the radiological impact, other than applying the conditions defined in the RMP for the CPP. Note that releases to the aquatic pathways that may impact on members of the public are not expected.

Table 14-4: Potential radiological impact rating during the operational phase of the Central Processing Plant.

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological Impact to members of the public induced by the Central Processing Plant, with dust inhalation the only contributing pathway.					
Prior to mitigation/management					
Intensity	Minimal impact	1	The only contribution is from dust inhalation, which is low due to low levels of PM_{10} that will be released from the CPP stacks	-14	Low (Negative)
Extent	Very limited	1	The radiological impact is very limited, and mainly limited to the site itself		
Duration	Project life	5	The impact, although low, will occur for the during of the project		
Probability	Improbable	2	It is improbable that a radiological impact above the compliance criteria will occur from releases from the CPP		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-70 to be submitted and approved by the NNR					

The RTSF serve as a potential sources of radiation exposure to members of the public through the atmospheric and groundwater pathways. In terms of the atmospheric pathway, radon gas and dust particles containing naturally occurring radionuclides are released into the atmosphere through wind erosion. These radon gas, as the main contributor, and dust particles (PM_{10}) are either inhaled, or some of the dust particles (TSP) are deposited in the environment that introduce secondary radiation exposure pathways. The area of impact from these entities is in the opposite directions. The radiation doses, especially in close proximity of the RTSF is moderate with a local area of impact. With distance away from the RTSF the doses as well within the compliance criteria (dose constraint). One can expect this situation to continue for as long as the RTSF remains a source at surface (permanent), with a good probability that the impact in close proximity of the RTSF will occur. The resulting radiological impact rating presented in Table 14-5 suggests a **Medium Low (negative) impact**.

Mitigation measures for radon inhalation as the main contributor is a covering layer to reduce the radon exhalation rate. This is potentially a very expensive measure and should be considered only as part of the revegetation of the RTSF to reduce the dust load. A covering layer of 0.25 m, for example, may result in a reduction of the radon inhalation dose by a third. However, as shown in Table 14-5, the application of the mitigation measure still results in a **Medium Low (negative) impact**.

Table 14-5: Potential radiological impact rating during the operational phase of the RTSF (atmospheric pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	**Rating**
Impact Description: Radiological impact induced by the RTSF during the operational phase, with atmospheric releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Moderate	3	The intensity is rated is moderate, since the radiological impact through the atmospheric pathway resulted in moderate doses, especially in close proximity of the RTSF (with radon inhalation as the main contributor).	-52	Medium Low (Negative)
Extent	local	3	The impact is highest close to the RTSF, but then decrease significantly with distance away from the RTSF.		
Duration	Permanent	7	Although moderate, the impact will continue to occur for as long as the RTSF remain as a source.		
Probability	Probable	4	The probability that the radiological impact will occur during the operational period is good		
Nature	Negative	-1			
Mitigation or management actions:					
While mitigation measures are not essential, applying covering layer will reduce the radon exhalation rate and the doses accordingly. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-70 to be submitted and approved by the NNR					
Intensity	Minor	2	The intensity is rated is minor, since the radiological impact through the atmospheric pathway resulted in minor doses, especially in close proximity of the RTSF (with radon inhalation as the main contributor).	-48	Medium Low (Negative)
Extent	local	3	The impact is highest close to the RTSF, but then decrease significantly with distance away from the RTSF.		
Duration	Permanent	7	Although minor, the impact will continue to occur for as long as the RTSF remain as a source.		
Probability	Probable	4	The probability that the radiological impact will occur during the operational period is remains good		
Nature	Negative	-1			

In addition to the atmospheric pathway, water containing radionuclides leach to the underlying aquifer, from where it may migrate laterally along the natural groundwater flow gradient to a point of abstraction of discharge. Abstraction and use of contaminated groundwater introduces secondary radiation exposure pathways. However, during the operational period is doses from the groundwater pathway is insignificant (minimal), and very limited in extent, but will continue to manifest itself for long as the RTSF remains at surface. However, it is improbable that the impact above the compliance criteria will occur during the operational period of the RTSF. The resulting radiological impact rating presented in Table 14-6 suggests a **Low (negative) impact**. No mitigation measures are required to reduce the radiological impact, other than applying the conditions defined in the RMP for the RTSF.

Table 14-6: Potential radiological impact rating during the operational phase of the RTSF (groundwater pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the RTSF during the operational phase, with groundwater as the contributing pathway.					
Prior to mitigation/management					
Intensity	Minimal impact	1	The intensity is rated is minimal, since the radiological impact through the groundwater pathway will in all likelihood not occur during the operational period, but only in hundreds of thousands of years post-closure.	-18	Low (Negative)
Extent	Limited	1	The impact during the operational period will be limited to the site itself.		
Duration	Permanent	7	Although minimal, the impact that will occur is permanent.		
Probability	Improbable	2	It is improbable that a radiological impact above the compliance criteria will occur from releases from the RTSF through the groundwater pathway		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-70 to be submitted and approved by the NNR					

The AWTF itself does not serve as a source of radiation exposure to members of the public. The facility is in a physical secured area, while no releases to the environment is expected from the facility itself. However, the purpose of the facility is to purify contaminated water to drinking water standards, after which it will be released to the environment for use *via* the Leeuspruit. The radiological impact was determined assuming the treated water is used to sustain a Commercial Agricultural Exposure Condition. The resulting doses were minor, with a very limited extent. Downstream the doses will decrease due to dilution. The water will be treated for the duration of the WRTRP and probably thereafter as well. If they can achieve the proposed treatment levels, it is improbable that a radiological impact above the compliance criteria will occur. The resulting radiological impact rating presented in Table

14-7 suggests a **low (negative) impact**. No mitigation measures are required to reduce the radiological impact, other than applying the conditions defined in the RMP for the AWTF.

Table 14-7: Potential radiological impact rating during the operational phase of the AFTF (surface water pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the release of treated water from the AWTF to the Leeuspruit.					
Prior to mitigation/management					
Intensity	Minor	2	The intensity is rated is minor, with low doses from using the water to sustain a Commercial Agricultural Exposure Condition.	-16	Low (Negative)
Extent	Very limited	1	The impact during the operational period will be limited to the site itself. Downstream the water will be diluted and the radiological impact will decrease.		
Duration	Permanent	5	The impact will occur for the during of the project		
Probability	Improbable	2	It is improbable that a radiological impact above the compliance criteria will occur from releases of water from the AWTR into the Leeuspruit		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective, since the total effective doses calculated from the treated water is already well below the public dose constraint.					
The facility will be managed and operated within the Radiation Management Programme for CoR-70 to be submitted and approved by the NNR					

The management actions for the operational period is to comply with the conditions set out in CoR-70, including the implementation and execution of management and control programmes and procedures. These include (amongst others) the *Occurrence Reporting Procedure,* the *Physical Security Procedure*, the *Emergency Preparedness and Response Procedure*, as well as the *Public Radiation Protection Programme.* The latter in particular ensures that any releases to the environment are monitored and that members of the public are protected from adverse exposure to ionizing radiation.

14.2.3 Post-Closure Phase

The only project activity that remains a source of radiation exposure during the post-closure phase is the RTSF itself. Deposition of tailings would have ceased. The remainder of the WRTRP components and associated surface infrastructure are assumed to be decommissioned and closed, and the surface areas cleaned up to pre-determined radiation levels.

During the post-closure period, the RTSF will continue to serve as a source of radiation exposure to members of the public, since radon gas and dust particles containing naturally occurring radionuclides are still released into the atmosphere through wind erosion. These radon gas and dust particles are either inhaled, or the dust particles are deposited in the environment that introduce secondary radiation exposure pathways. The radiological impact rate during the post-closure period presented in Table 14-8 remains **Medium-Low (negative)**, mainly because the radon inhalation will continue to be the main contributor. The same applies to the implementation of mitigation measures.

Table 14-8: Potential radiological impact rating during the post-closure phase of the RTSF (atmospheric pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	**Rating**
Impact Description: Radiological impact induced by the RTSF during the operational phase, with atmospheric releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Moderate	3	The intensity is rated is moderate, since the radiological impact through the atmospheric pathway resulted in moderate doses, especially in close proximity of the RTSF (with radon inhalation as the main contributor).	-52	Medium Low (Negative)
Extent	local	3	The impact is highest close to the RTSF, but then decrease significantly with distance away from the RTSF.		
Duration	Permanent	7	Although moderate, the impact will continue to occur for as long as the RTSF remain as a source during the post-closure period		
Probability	Probable	4	The probability that the radiological impact will occur during the post-closure period is good		
Nature	Negative	-1			
Mitigation or management actions:					
While mitigation measures are not essential, applying covering layer will reduce the radon exhalation rate and the doses accordingly. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-70 to be submitted and approved by the NNR					
Intensity	Minor	2	The intensity is rated is minor, since the radiological impact through the atmospheric pathway resulted in minor doses, especially in close proximity of the RTSF (with radon inhalation as the main contributor).	-48	Medium Low (Negative)
Extent	local	3	The impact is highest close to the RTSF, but then decrease significantly with distance away from the RTSF.		
Duration	Permanent	7	Although minor, the impact will continue to occur for as long as the RTSF remain as a source.		

Probability	Probable	4	The probability that the radiological impact will occur during the operational period is remains good		
Nature	Negative	-1			

In addition to the atmospheric pathway, water containing radionuclides still leach to the underlying aquifer, from where it migrates laterally along the groundwater flow gradient. Abstraction and use of contaminated groundwater introduces secondary radiation exposure pathways. However, it was illustrated that it will still take hundreds of thousands of years for the contaminant plume to migrate of few hundred metres, which resulted in an impact rating of **Low (negative)** as shown in Table 14-9.

Table 14-9: Potential radiological impact rating during the post-closure phase of the RTSF (groundwater pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the RTSF during the post-closure operational phase, with groundwater as the contributing pathway.					
Prior to mitigation/management					
Intensity	Minimal impact	1	The intensity is rated is minimal, since the radiological impact through the groundwater pathway during the post-closure period, will probably only occur in hundreds of thousands of years post-closure.	-30	Low (Negative)
Extent	Limited	2	The impact during the post-closure period will be limited to the immediate surroundings, probably not more than a few hundred metres from RTSF site itself.		
Duration	Permanent	7	Although minimal, the impact that will occur is permanent.		
Probability	Unlikely	3	The probability that the radiological impact will occur during the post-closure period is still unlikely, mainly due to the timescales of concern		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-70 to be submitted and approved by the NNR					

14.3 Driefontein Mining Right Area Impact Assessment

The main WRPRP activities to consider from a radiological public impact perspective for the Driefontein Mining Right area, are the surface infrastructure for the pipelines and booster pump stations, the West Block Thickeners, the Bulk Water Storage Facility, as well as the reclamation of the historical TSFs (Driefontein No. 3 TSF and Driefontein No. 5 TSF) with its associated surface infrastructure (e.g. Pollution Control Dams).

14.3.1 Construction Phase

No material containing naturally occurring radionuclides are used or handled during the construction phase, and as a result there is no additional radiological impact to members of the public associated with the Driefontein Mining Right area during this phase. The radiological impact is expected to be the same as current conditions, especially for the historical TSFs (i.e., the Driefontein No. 3 TSF and Driefontein No. 5 TSF).

14.3.2 Operational Phase

The project activities associated with the Driefontein Mining Right area that were considered as potential sources of public radiation exposure for the operational phase, are the reclamation of the historical TSF.

The West Block Thickeners and the BWSF will be located in a secured area with no releases to the environment and therefore were excluded as potential sources of radiation exposure. In addition, and under normal operating conditions, the surface infrastructure for the pipelines and the booster pump stations are not considered as sources of radiation exposure to members of the public.

The reclamation process is a wet process, which means that dust generation will be reduced, while the wetter conditions will also reduce the radon exhalation rate from the TSF during reclamation. Based on experience of operating TSFs, moderate doses are associated with the atmospheric pathway during operations, with radon inhalation the main contributor. The doses are highest close to the TSF, but decrease significantly with distance away from the source, leaving a local area of extent. Although moderate the impact will continue to occur as long as the TSF remains at surface. There is a probable change that some of the doses, especially close to the TSF, will be above the dose constraint of 250 $\mu Sv.y^{-1}$. The resulting radiological impact rating presented in Table 14-10 suggests a **Medium-Low (negative) impact**. No mitigation measures are required to reduce the radiological impact during the operational phase, other than applying the conditions defined in the RMP for the TSF. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.

The introduction of more water into the system might have a slight increase in the seepage rate (relative to the total TSF) to the underlying aquifer during reclamation and thus, at least in principle, enhance the formation of a contaminant plume. Abstraction and use of contaminated groundwater introduces secondary radiation exposure pathways. However, during the operational period is doses from the groundwater pathway is insignificant (minimal), and very limited in extent, but will continue to manifest itself for long as the TSF remains at surface. However, it is improbable that the impact above the compliance criteria will occur during the operational period of the TSF. The resulting radiological impact rating presented in Table 14-11 suggests **Low (negative) impact**. No mitigation measures are required to reduce the radiological impact, other than applying the conditions defined in the RMP for the TSF. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.

Table 14-10: Potential radiological impact rating during the operational phase of the Driefontein reclamation process (atmospheric pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the reclamation of the Driefontein TSFs, with atmospheric releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Moderate	3	The intensity is rated is moderate, since the radiological impact through the atmospheric pathway resulted in moderate doses, especially in close proximity of the TSFs (with radon inhalation as the main contributor).	-52	Medium Low (Negative)
Extent	local	3	The impact is highest close to the TSFs, but then decrease significantly with distance away from the TSFs.		
Duration	Permanent	7	Although moderate, the impact will continue to occur for as long as the TSF remain as a source.		
Probability	Probable	4	The probability that the radiological impact will occur during the operational period is good		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-69 to be submitted and approved by the NNR					

14.3.3 Post-Closure Phase

The reclamation and thus the removal of the historical TSFs as a potential contaminant source will have a positive impact on public radiation exposure conditions in the vicinity of the TSFs. This is under the assumption that the total footprint areas of the TSFs are rehabilitated and cleaned and that no residual tailings are left that may still serve as a source area. This will immediately eliminate any contribution through the atmospheric pathway (serious impact) over the area of impact, with a permanent benefit to members of the public. There is thus a strong possibility that the positive impact will occur (definite). The resulting impact assessment rating is presented in Table 14-12, which suggest a **Moderate (positive) impact**.

However, it should be kept in mind that the TSFs are not lined and therefore contaminants have seeped into the underlying soils and aquifer system during operation, resulting in the formation of secondary sources beneath the historical TSFs. The level of contamination and associated mitigation measures that would be required to clean the contaminated aquifer can only be characterised and determined once the TSFs are removed, which will also have an influence on the final land use condition (see Table 14-12).

Table 14-11: Potential radiological impact rating during the operational phase of the Driefontein reclamation process (groundwater pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the reclamation of the Driefontein TSFs, with groundwater releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Minimal impact	1	The intensity is rated is minimal, since a radiological impact through the groundwater pathway will in all likelihood not occur during the operational period, due to the slow leaching and migration processes.	-27	Low (Negative)
Extent	Limited	1	The impact during the operational period will be limited to the site itself.		
Duration	Permanent	7	Although minimal, the impact that will occur is permanent.		
Probability	Unlikely	3	The probability that the radiological impact will occur during the operational period is unlikely		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-69 to be submitted and approved by the NNR					

14.4 Cooke Mining Right Area Impact Assessment

The main WRPRP activities to consider from a radiological public impact perspective for the Cooke Mining Right area, are the abstraction of water from the Cooke shafts, the surface infrastructure for the pipelines and booster pump stations, the Block Thickeners, the Bulk Water Storage Facility, as well as the reclamation of the historical TSFs (Cooke TSF and Cooke 4 South TSF) with its associated infrastructure (e.g. Pollution Control Dams).

14.4.1 Construction Phase

No material containing naturally occurring radionuclides are used or handled during the construction phase, and as a result there is no additional radiological impact to members of the public associated with the Cooke Mining Right area during this phase. The radiological impact is expected to be the same as current conditions, especially for the historical TSFs (i.e., the Cooke TSF and Cooke 4 South TSF).

14.4.2 Operational Phase

The project activities associated with the Cooke Mining Right area that were considered as potential sources of public radiation exposure for the operational phase, are the reclamation of the historical TSFs.

Table 14-12: Potential radiological impact rating during the post-closure phase for the removal of the Driefontein TSFs.

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the reclamation and subsequent removal of the Driefontein TSFs during the post-closure period.					
Prior to mitigation/management					
Intensity	Serious	5	Serious radiological benefits can be expected once the TSFs are removed as sources of radiation exposure	105	Moderate (Positive)
Extent	Local	3	The impact is expected to be local		
Duration	Permanent	7	The elimination of radionuclides distributed into the environment that may contribute to radiation exposure is excepted to be permanent.		
Probability	Definite	7	There is a strong possibility that the positive impact will definitely occur		
Nature	Positive	1			
Mitigation or management actions:					
Rehabilitation of the TSF footprint areas. Establish the level of groundwater contamination beneath the historical TSF site through monitoring.					
Post mitigation					
Intensity	Serious	5	Serious radiological benefits can be expected once the TSFs are removed as sources of radiation exposure and the footprint areas rehabilitated	105	Moderate (Positive)
Extent	Local	3	The impact is expected to be local		
Duration	Permanent	7	The elimination of radionuclides distributed into the environment that may contribute to radiation exposure is excepted to be permanent.		
Probability	Definite	7	There is a strong possibility that the positive impact will definitely occur		
Nature	Positive	1			

The Block Thickeners and the Bulk Water Storage Facility will be located in a secured area with no releases to the environment and therefore were excluded as potential sources of radiation exposure. In addition, and under normal operating conditions, the surface infrastructure for the pipelines and the booster pump stations are not considered as sources of radiation exposure to members of the public, while the physical abstraction of water from the Cooke shafts was screened out as a potential source of radiation exposure.

The reclamation process is a wet process, which means that dust generation will be reduced, while the wetter conditions will also reduce the radon exhalation rate from the TSF during reclamation. Based on experience of operating TSFs, moderate doses are associated with the atmospheric pathway during operations, with radon inhalation the main contributor. The doses are highest close to the TSF, but decrease significantly with distance away from the source, leaving a local area of extent. Although moderate the impact will continue to occur as long as the TSF remains at surface. There is a probable change that some of the doses, especially close to the TSF, will be above the dose constraint of 250 $\mu Sv.y^{-1}$. The resulting radiological impact rating presented in Table 14-13 suggests a **Medium-Low (negative) impact**. No mitigation measures are required to reduce the radiological impact during the operational phase, other than applying the conditions defined in the RMP for the TSF. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.

Table 14-13: Potential radiological impact rating during the operational phase of the Cooke reclamation process (atmospheric pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the reclamation of the Cooke TSF, with atmospheric releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Moderate	3	The intensity is rated is moderate, since the radiological impact through the atmospheric pathway resulted in moderate doses, especially in close proximity of the TSFs (with radon inhalation as the main contributor).	-52	Low (Negative)
Extent	local	3	The impact is highest close to the TSFs, but then decrease significantly with distance away from the TSFs.		
Duration	Permanent	7	Although moderate, the impact will continue to occur for as long as the RTSF remain as a source.		
Probability	Probable	4	The probability that the radiological impact will occur during the operational period is good		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-226 to be submitted and approved by the NNR					

The introduction of more water into the system might have a slight increase in the seepage rate (relative to the total TSF) to the underlying aquifer during reclamation and thus, at least in principle, enhance the formation of a contaminant plume. Abstraction and use of contaminated groundwater introduces secondary radiation exposure pathways. However, during the operational period is doses from the groundwater pathway is insignificant (minimal), and very limited in extent, but will continue to manifest itself for long as the TSF remains at surface. However, it is improbable that the impact above the compliance criteria will occur during the operational period of the TSF. The resulting radiological impact rating presented in Table 14-14 suggests **Low (negative) impact**. No mitigation measures are required to reduce the radiological impact, other than applying the conditions defined in the RMP for the TSF. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.

Table 14-14: Potential radiological impact rating during the operational phase of the Cooke reclamation process (groundwater pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the reclamation of the Cooke TSFs, with groundwater releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Minimal impact	1	The intensity is rated is minimal, since a radiological impact through the groundwater pathway will in all likelihood not occur during the operational period, due to the slow leaching and migration processes.	-27	Low (Negative)
Extent	Limited	1	The impact during the operational period will be limited to the site itself.		
Duration	Permanent	7	Although minimal, the impact that will occur is permanent.		
Probability	Unlikely	3	The probability that the radiological impact will occur during the operational period is unlikely		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-226 to be submitted and approved by the NNR					

14.4.3 Post-Closure Phase

The reclamation and thus the removal of the historical TSFs as a potential contaminant source will have a positive impact on public radiation exposure conditions in the vicinity of the TSFs. This is under the assumption that the total footprint areas of the TSFs are rehabilitated and cleaned and that no residual tailings are left that may still serve as a source area. This will immediately eliminate any contribution through the atmospheric pathway (serious impact) over the area of impact, with a permanent benefit to members of the public. There is thus a strong possibility that the positive impact will occur (definite). The resulting impact assessment rating is presented in Table 14-15, which suggest a **Moderate (positive) impact**.

However, it should be kept in mind that the TSFs are not lined and therefore contaminants have seeped into the underlying soils and aquifer system during operation, resulting in the formation of secondary sources beneath the historical TSFs. The level of contamination and associated mitigation measures that would be required to clean the contaminated aquifer can only be characterised and determined once the TSFs are removed, which will also have an influence on the final land use condition (see Table 14-15).

Table 14-15: Potential radiological impact rating during the post-closure phase for the removal of the Cooke TSFs.

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the reclamation and subsequent removal of the Cooke TSFs during the post-closure period.					
Prior to mitigation/management					
Intensity	Serious	5	Serious radiological benefits can be expected once the TSFs are removed as sources of radiation exposure	105	Moderate (Positive)
Extent	Local	3	The impact is expected to be local		
Duration	Permanent	7	The elimination of radionuclides distributed into the environment that may contribute to radiation exposure is excepted to be permanent.		
Probability	Definite	7	There is a strong possibility that the positive impact will definitely occur		
Nature	Positive	1			
Mitigation or management actions:					
Rehabilitation of the TSF footprint areas. Establish the level of groundwater contamination beneath the historical TSF site through monitoring.					
Post mitigation					
Intensity	Serious	5	Serious radiological benefits can be expected once the TSFs are removed as sources of radiation exposure and the footprint areas rehabilitated	105	Moderate (Positive)
Extent	Local	3	The impact is expected to be local		
Duration	Permanent	7	The elimination of radionuclides distributed into the environment that may contribute to radiation exposure is excepted to be permanent.		
Probability	Definite	7	There is a strong possibility that the positive impact will definitely occur		
Nature	Positive	1			

14.5 Ezulwini Mining Right Area Impact Assessment

The main WRPRP activities to consider from a radiological public impact perspective for the Ezulwini Mining Right area, are the abstraction of water from the Ezulwini shafts, the surface infrastructure for the pipelines and booster pump stations, and the Bulk Water Storage Facility.

The processing of the uranium concentrate from the CPP at the Ezulwini plant is still within the design (and approved) parameters of the plant and does not require additional consideration. The same applies to the deposition of the resulting tailings from the processing at the Ezulwini North TSF, since the facility is already approved for a deposition rate of 100 Mt per month.

14.5.1 Construction Phase

No material containing naturally occurring radionuclides are used or handled during the construction phase, and as a result there is no additional radiological impact to members of the public associated with the Ezulwini Mining Right area during this phase. The radiological impact is expected to be the same as current conditions.

14.5.2 Operational Phase

The project activities associated with the Ezulwini Mining Right area that were considered as potential sources of public radiation exposure for the operational phase, are the reclamation of the historical TSF.

The Bulk Water Storage Facility will be located in a secured area with no releases to the environment and therefore were excluded as potential sources of radiation exposure. In addition, and under normal operating conditions, the surface infrastructure for the pipelines and the booster pump stations are not considered as sources of radiation exposure to members of the public, while the physical abstraction of water from the Ezulwini shafts was screened out as a potential source of radiation exposure.

14.5.3 Post-Closure Phase

The only project activity that remains a source of radiation exposure during the post-closure phase is the Ezulwini North TSF itself. Deposition of tailings would have ceased. The remainder of the WRTRP components and associated surface infrastructure are assumed to be decommissioned and closed, and the surface areas cleaned up to pre-determined radiation levels.

During the post-closure period, the Ezulwini North TSF will continue to serve as a source of radiation exposure to members of the public, since radon gas and dust particles containing naturally occurring radionuclides are still released into the atmosphere through wind erosion. These radon gas and dust particles are either inhaled, or the dust particles are deposited in the environment that introduce secondary radiation exposure pathways. The radiological impact rate during the post-closure period presented in Table 14-8 remains **Medium-Low (negative)**, mainly because the radon inhalation will continue to be the main contributor. The same applies to the implementation of mitigation measures.

In addition to the atmospheric pathway, water containing radionuclides still leach to the underlying aquifer, from where it migrates laterally along the groundwater flow gradient. Abstraction and use of contaminated groundwater introduces secondary radiation exposure pathways. However, it was illustrated that it will still take hundreds of thousands of years for the contaminant plume to migrate of few hundred metres, which resulted in an impact rating of **Low (negative)** as shown in Table 14-9.

Table 14-16: Potential radiological impact rating during the post-closure phase of the Ezulwini North TSF (atmospheric pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the Ezulwini North TSF during the post-closure phase, with atmospheric releases as the contributing pathway.					
Prior to mitigation/management					
Intensity	Moderate	3	The intensity is rated is moderate, since the radiological impact through the atmospheric pathway resulted in moderate doses, especially in close proximity of the Ezulwini North TSF (with radon inhalation as the main contributor).	-52	Medium Low (Negative)
Extent	local	3	The impact is highest close to the Ezulwini North TSF, but then decrease significantly with distance away from the Ezulwini North TSF.		
Duration	Permanent	7	Although moderate, the impact will continue to occur for as long as the Ezulwini North TSF remain as a source during the post-closure period		
Probability	Probable	4	The probability that the radiological impact will occur during the post-closure period is good		
Nature	Negative	-1			
Mitigation or management actions:					
While mitigation measures are not essential, applying covering layer will reduce the radon exhalation rate and the doses accordingly. It may be that mitigation measure from an air quality perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-58 to be submitted and approved by the NNR					
Intensity	Minor	2	The intensity is rated is minor, since the radiological impact through the atmospheric pathway resulted in minor doses, especially in close proximity of the Ezulwini North TSF (with radon inhalation as the main contributor).	-48	Medium Low (Negative)
Extent	local	3	The impact is highest close to the Ezulwini North TSF, but then decrease significantly with distance away from		

			the Ezulwini North TSF.		
Duration	Permanent	7	Although minor, the impact will continue to occur for as long as the Ezulwini North TSF remain as a source.		
Probability	Probable	4	The probability that the radiological impact will occur during the operational period is remains good		
Nature	Negative	-1			

Table 14-17: Potential radiological impact rating during the post-closure phase of the Ezulwini North TSF (groundwater pathway).

Dimension	Rating	Score	Motivation	Significance	
				Score	Rating
Impact Description: Radiological impact induced by the Ezulwini North TSF during the post-closure operational phase, with groundwater as the contributing pathway.					
Prior to mitigation/management					
Intensity	Minimal impact	1	The intensity is rated is minimal, since the radiological impact through the groundwater pathway during the post-closure period, will probably only occur in hundreds of thousands of years post-closure.	-30	Low (Negative)
Extent	Limited	2	The impact during the post-closure period will be limited to the immediate surroundings, probably not more than a few hundred metres from Ezulwini North TSF site itself.		
Duration	Permanent	7	Although minimal, the impact that will occur is permanent.		
Probability	Unlikely	3	The probability that the radiological impact will occur during the post-closure period is still unlikely, mainly due to the timescales of concern		
Nature	Negative	-1			
Mitigation or management actions:					
No mitigation measures are required from a radiological perspective. It may be that mitigation measure from a groundwater perspective is proposed that will have a direct influence in the radiological impact as well.					
The facility will be managed and operated within the Radiation Management Programme for CoR-58 to be submitted and approved by the NNR					

15 Cumulative Impacts

A distinction can be made between (i) the cumulative impact between different facilities or activities included within the scope of the same CoR or (ii) the cumulative impact between facilities and activities belonging to different CoRs.

The national safety standards and regulatory compliance criteria is clear that members of the public should be protection from *all* contributing sources or operations. In terms of national and international regulations, the total effective dose from all these sources should be below 1 $mSv.a^{-1}$ (or 1000 $µSv.a^{-1}$). The national safety standards also make provision for the application of a dose constraint od 0.25 $mSv.a^{-1}$ (or 250 $µSv.a^{-1}$).

15.1 Cumulative impact within a CoR

Due to the nature of most mining and mineral processing operations, a cumulative radiological impact may be expected between different facilities within the same CoR, especially where facilities are closely (spatially) associated with each other. Viewed from a radiation protection perspective, each CoR is licensed separately, which means that the cumulative effect between all potential sources included in the scope of that CoR should be within the compliance criteria set for public exposure.

Within the Driefontein Mining Right area, the cumulative effect as far as the WRTRP is concern will in all likelihood be a reduction in the total effective dose, since the Driefontein No. 3 and Driefontein No. 5 TSFs are major sources that will be removed from the system, with a significant reduction in the radiological impact near these facilities.

Within the Cooke Mining Right area, the situation as far as the WRTRP is concern is expected to be similar, with the removal of the Cooke and Cook4 South TSF as sources and the net effect of a reduction in the total effective dose and thus the radiological impact near these facilities (see Section 12.2).

Within the Ezulwini Operations Mining Right area, the cumulative effect as far as the WRTRP is concern is expected to be minimal, as no significant changes are expected. The inpout and output from the process plant is still within the design parameters for which it was approved, while, the additional deposition on the Ezulwini North TSF is also within its design parameters. If any, the contribution from the TSF will be lower due to lower activity concentrations in the deposited material originating from the WRTRP, oppose to current values (see Section 12.3).

Within the Kloof Operations Mining Right area, the cumulative effect as far as the WRTRP is concern is expected to be less significant. The CPP is a new potential source of radiation exposure, but with a minimal radiological impact as illustrated in Section 12.4.2. The contribution from the RTSF and its associated components to a radiological impact, on the other hand, is expected to be more significant. The RTSF is located in an area where contribution from some facilities within the Scope of CoR-70 may overlap, resulting in a cumulative radiological impact.

It can thus be concluded that the cumulative radiological impact from the WRTRP within each CoR (or Mining Right area) will be similar or less to the current radiological impact, with the exception of the Kloof Mining Right area, where the RTSF may result in additional contributions to the total effective dose in currently impacted areas.

15.2 Cumulative impact between CoRs

Some mining and mineral processing operations are isolated and members of the public will potentially be subject to radiation exposure conditions from only the one operation. Under these conditions, the public dose limit of 1 mSv per annum applies, although the regulator may still apply the dose constraint concept (0.25 mSv per annum) depending on site specific conditions. Given the scope and spatial extent of CoR-69, as well as the Driefontein components of the WRTRP, it is reasonable to assume that there will be no cumulative impact between the Driefontein Operations and any of the other CoRs.

Some other mining and mineral processing operations operating under different CoRs are closely associated with each other, of which the Cooke and Ezulwini Operations are a good example. The cumulative effect between the two operations under current operating conditions was clearly illustrated in Section 12.2 (see Figure 12-3). The important factor is that the cumulative total effective dose to members of the public should not be more than the dose limit of 1 mSv per annum, which means that the dose constraint should be applied. However, the positive impact of the WRTRP by removing the Cooke 4 South TSF as a source will result in a decrease in the total effective dose, resulting in a positive cumulative impact between the two CoRs (see Figure 12-4). The cumulative impact between these two operations can easily be managed, since they both belong to Sibanye.

A slightly different situation exists within the Kloof Operation, and in particular in the vicinity of the RTSF. The RTSF and its associated components are slightly isolated as far as other facilities within the Kloof Operations are concern. However, as illustrated in Figure 7-9, the Gold Fields Doornpoort facility are located within 2 km from the RTSF, which means that a cumulative impact is possible. More important is the fact that the radon dispersion is in the direction of the Doornpoort TSF. This assessment addressed only the contribution from the RTSF. It is outside the scope of this report to address the issue of a regional assessment, in which case the contribution from *all* contributing facilities or operations will be considered. For a regional assessment, the *dose limit* will be applicable, whereas for facility specific assessments the *dose constraint* is more applicable, especially to address the issue of multiple contributions. This means that the cumulative contribution from the Doornpoort TSF, the RTSF and any other facility in the area may not exceed 1 mSv per annum for a reasonable public exposure condition.

It is worth noting that the radon inhalation dose contribution from the RTSF is relatively high due to the size of the facility. This means that the contribution from the Doornpoort TSF, which is smaller, will be less. It was also illustrated that the radon inhalation dose decreases significantly with distance away from the facility (see Figure 12-10). Figure 13-1, for example, showed that the 200 µSv per annum isopleth is relatively close to the RTSF, which suggests that a cumulative impact between the two facilities will in all likelihood still be within the dose limit and even the dose constraint.

16 Unplanned Events and Low Risks

Low risks can be monitored to gauge if the baseline changes and mitigation is required, while unplanned events outside the normal operating conditions may happen on any project. The potential radiological impact for most components associated with the WRTRP is gradual processes, and does not necessarily falls within the category of unplanned events and low risks.

The exception is occurrences such as accidents and incidents, which include for example (i) uncontrolled releases of water to the environment, and (ii) pipeline bursts. Examples of uncontrolled releases of water to the environment include overflow situations during flooding (e.g. the RWD) or spillages at facilities designed for zero release to the environment. Pipelines is used extensively in the process to transfer water, tailings of concentrate material between facilities. The possibility that pipeline bursts can occur for water or solids, overland and at river/stream crossings, cannot be excluded.

The *suite* of documents that have to be prepared and submitted to the NNR for approval as part of the overall RMP include an *Occurrence Reporting Procedure* This procedure, together with the *Physical Security Procedure*, the *Emergency Preparedness and Response Procedure*, as well as the *Public Radiation Protection Programme*, ensure that any of such events are timely identified and reported to the NNR, and properly mitigated based on an NNR approved action plan before it can cause a significant public radiation exposure situation.

The closeout report prepared for this purpose may include additional mitigation, clean-up and monitoring actions to be implemented. Viewed from a radiological impact perspective, it is important to note that these occurrences are site and event specific, that *might* occur. For this reason, these events are treated on a case-by-case basis. The potential radiological consequences tend to be of low significance if managed within the conditions defined in the RMP. A number of reason contribute to this fact:

- The occurrence reporting procedure as part of the radiation management plan requires immediate action to report, contain, rectify and mitigate the event.
- As a result, the duration of these events tends to be relatively short, which means that the potential exposure period relative to an annual exposure period to members of the public is short.
- Dilution of dirty water with clean water is often associated with events of this nature, which reduces the potential radiological consequences.
- The process description also makes provision for the containment of spillages from pipelines if they do occur, especially at river of stream crossings.
- All facilities and activities where water is used are designed for a zero release to the environment principle, which means that water, if spilled will be contained and diverted back into the system.

- The RWD at the RTSF is designed to handle a 1:50 year flood in accordance with Regulation GN 704, which means that in adverse conditions contaminated water may be released to the environment, although highly unlikely.

17 Environmental Management Plan

The objective of an Environmental and Social Management Plan (ESMP) is to present mitigation measures to (a) manage undue or reasonably avoidable adverse impacts associated with the development of a project and to (b) enhance potential positives.

Note that each Mining Right area operates under its own CoR that requires the development and maintenance of a RMP that include various management programmes and procedures aimed at protecting human health and the environment in general. These programmes and procedures already developed for each CoR include the following (NNR, 2009):

- Worker and public safety assessment report;
- Worker and public radiation protection programmes;
- Integrated waste management programme;
- Radiation protection function;
- Transport procedure;
- Physical security procedure;
- Emergency procedure including occurrences; and
- Quality management procedure.

As part of the Authorisation Change Request (ACR) to be submitted to the NNR for the WRTRP, these programmes and procedures needs to be revised and updated to include new project components and to reflect changes brought into the Scope of the CoR. This means that physical security and radiation protection measures will be implemented as appropriate to prevent or mitigate uncontrolled access to facilities as part of the RMP. However, the same level of security cannot be implemented or is not necessary to be implemented for all project components, such as the pipelines (wide spread and low risk) and RTSF (physical size), for example.

In addition, some of the specialist studies (Digby Wells Environmental, 2015g; h; i) include mitigation measures to implement for the surface water, groundwater, or atmospheric pathways, for example. Some of these mitigation measures will by implication serve as radiation protection measures for members of the public. An example is the mitigation of wind erosion to reduce dust loads or the application of liners to reduce infiltration. This will have a direct impact on the radiological impact as well. Some of these mitigation measures may be repeated and discussed here as appropriate.

Finally, it should be noted that the radiological risks presented in this report all falls within the national criteria for the protection of members of the public from exposure to ionizing radiation. This means that any additional mitigation measures proposed here is more from a ALARA perspective than from a compliance perspective.

17.1 Kloof Mining Right Area

17.1.1 Construction Phase

Since there is no radiological impact associated with the construction phase, there is no mitigation measures necessary to implement from a radiation protection perspective. What is important though is to ensure that the baseline site characterisation of potentially impacted areas is completed before any construction commence.

Also important from a construction perspective is to ensure that the design features included in the different components of the WRTRP that will facilitate and enhance the containment of radionuclides that may be released to the environment, are implemented with the necessary quality assurance and quality controls considered.

17.1.2 Operational Phase

17.1.2.1 CPP

The radioactivity released to the environment in the form of inhalable dust particles (PM_{10}) from the CPP stacks is very low, resulting in a low radiological impact. Therefore, no mitigation measures are required for radiation exposure to members of the public, other than implementing an appropriate monitoring programme (see Section 17.6) and applying the ALARA principle.

For the prospective assessment presented here, the dose assessment was based on a conservative *estimate* of the activity concentration that will be released from the CPP stacks. Once the facility is operational, a sample of what is *actually* released from the stacks needs to be submitted to a Sanas accredited laboratory for full spectrum analysis (see Section 17.6).

17.1.2.2 RTSF

The RTSF is expected to release radioactivity to the environment through the groundwater and atmospheric pathways. The assessment confirmed that the groundwater pathway is very slow, and in all likelihood a radiological impact that requires mitigation will not be observed during the operational period. The groundwater impact assessment study (Digby Wells Environmental, 2015g) incorporated a number of scenarios consideration different mitigation measures, either as planned activities or as additional mitigation measures. Any of these mitigation measures will reduce the probability of a radiological impact even further. However, from a public radiation protection perspective, no additional mitigation measures are required for the groundwater pathway, other than implementing a groundwater monitoring programme to confirm the absence or the development of a contaminant plume (see Section 17.6).

The atmospheric pathway differs from the groundwater pathway in the sense that the potential radiological impact to members of the public is from commissioning. Any dust control measures proposed as part of the air quality impact assessment (Digby Wells Environmental, 2015h) will reduce the probability of a radiological impact. However, it was illustrated that radon inhalation is the biggest contributor to the total effective dose. The radon inhalation dose is highest at the RTSF and decrease with distance away from the TSF in a northerly direction to less than 100 μSv on the northern side of the Leeuspruit. Implementing a cover layer to facilitate revegetation as part of the phased implementation of the RTSF, will reduce the radon exhalation rate and thus the radon inhalation dose. In addition, the implementing an environmental radon monitoring programme is proposed (see Section 17.6).

For the prospective assessment presented here, the dose assessment was calculated based on a conservative *estimate* of what the activity concentration in the RTSF tailings would be. Once the facility is operational, a sample of the *actually* tailings needs to be submitted for full spectrum analysis (see Section 17.6).

17.1.2.3 RWD

No radiological impact is foreseen for the RWD during the operational phase. All mitigation measures proposed as part of the groundwater impact assessment (Digby Wells Environmental, 2015g) will further reduce the probability of a radiological impact. From a public radiation protection perspective, no additional mitigation measures are therefore required for the groundwater pathway, other than implementing a groundwater monitoring programme to confirm the absence or the development of a contaminant plume (see Section 17.6).

17.1.2.4 AWTF

The total effective dose calculated for a Commercial Agricultural Exposure Conditions from water released from the AWTF into the environment, suggests that no mitigation measure is required. However, the results are based on a conservative estimate of what the water activity concentration might be, if the facility performed as planned and designed. Once the facility is operational, actual samples of what is released from the facility should be submitted to a Sanas accredited laboratory for full spectrum analysis on a regular basis to build confidence in the performance of the facility (see Section 17.6).

17.1.3 Post-Closure

Only the RTSF will remain as part of the Kloof Mining Right area during the post-closure phase. The facility will continue to have a potential impact through the groundwater and atmospheric pathway. It was illustrated that the impact through the groundwater pathway will manifest itself only in hundreds of thousands of years post-closure. Any mitigation measures proposed as part of the groundwater impact assessment (Digby Wells Environmental, 2015g) will contribute to a reduction in the total effective dose, but due to the timescales of concern will in all likelihood be insignificant. Any mitigation measures proposed as part of the air quality impact assessment (Digby Wells Environmental, 2015h) will contribute to a reduction in the total effective dose, of which the application and implementation of soil covering layers and revegetation will be the most effective to reduce dust levels and to reduce the radon exhalation rate.

17.2 Driefontein Mining Right Area

17.2.1 Construction Phase

Since there is no radiological impact associated with the construction phase, there is no mitigation measures necessary to implement from a radiation protection perspective. What is important though is to ensure that the baseline site characterisation of potentially impacted areas is completed before any construction commence.

Also important from a construction perspective is to ensure that the design features included in the different components of the WRTRP that will facilitate and enhance the containment of radionuclides that may be released to the environment, are implemented with the necessary quality assurance and quality controls considered.

17.2.2 Operational Phase

The West Block Thickener was excluded as a source of radiation exposure to members of the public, and therefore no mitigation measures are required for this facility.

The reclamation of the historical TSF areas in itself will have a significant positive radiological impact, since the source of radiation exposure is removed, both for the groundwater and the atmospheric pathways. Water used in the hydraulic reclamation processes will be retailed and recirculated as to present the of site releases of water. Additional mitigation measures are therefore not required, while the monitoring programme as part of the current public RPP is deemed sufficient for the purpose of the operational period.

Very important from an environmental and radiation management perspective is that the reclamation areas be rehabilitated and cleaned down to footprint level, i.e., complete removal of the surface source down to footprint level. Only once the footprint is reached will it be possible to characterise, quantify, and define the contamination and associated mitigation measures that would be require to clean up the contaminated groundwater beneath the historical TSF.

17.2.3 Post-Closure Phase

Since the facilities, including the historical TSFs will be removed from surface, no radiological impact that requires mitigation are associated with the post-closure phase.

17.3 Cooke Mining Right Area

17.3.1 Construction Phase

Since there is no radiological impact associated with the construction phase, there is no mitigation measures necessary to implement from a radiation protection perspective. What is important though is to ensure that the baseline site characterisation of potentially impacted areas is completed before any construction commence.

Also important from a construction perspective is to ensure that the design features included in the different components of the WRTRP that will facilitate and enhance the containment of radionuclides that may be released to the environment, are implemented with the necessary quality assurance and quality controls considered.

17.3.2 Operational Phase

The Block Thickener was excluded as a source of radiation exposure to members of the public, and therefore no mitigation measures are required for this facility.

The reclamation of the historical TSF areas in itself will have a significant positive radiological impact, since the source of radiation exposure is removed, both for the groundwater and the atmospheric pathways. Water used in the hydraulic reclamation processes will be retailed and recirculated as to present the of site releases of water. Additional mitigation measures are therefore not required, while the monitoring programme as part of the current public RPP is deemed sufficient for the purpose of the operational period.

Very important from an environmental and radiation management perspective is that the reclamation areas be rehabilitated and cleaned down to footprint level, i.e., complete removal of the surface source down to footprint level. Only once the footprint is reached will it be possible to characterise, quantify, and define the contamination and associated mitigation measures that would be require to clean up the contaminated groundwater beneath the historical TSF.

17.3.3 Post-Closure Phase

Since the facilities, including the historical TSFs will be removed from surface, no radiological impact that requires mitigation are associated with the post-closure phase.

17.4 Ezulwini Mining Right Area

All WRTRP activities associated with the Ezulwini Mining Right area falls within currently approved conditions for the processing and disposal of tailings material, and as a result no radiological impact are recorded that require additional mitigation measures to implement to reduce the potential radiological impact to members of the public.

17.5 Summary of Mitigation and Management

Section 17.1 to Section 17.4 provide a description of the mitigation and management options for the radiological impacts anticipated during the construction, operational and closure phases. The radiological impact assessment was performed in accordance with the provisions, requirements and regulations as promulgated in terms of the National Nuclear Regulator Act (Act 46 of 1999), with specific reference to Regulation 388 of April 2006. The latter specify the national safety standards for the protection of members of the public from exposure to ionizing radiation.

Following a Source-Pathway-Receptor analysis approach, public exposure conditions were defined. Using the air quality, groundwater and to a lesser extent the surface water specialist studies as basis, the radiological impact induced by the different components of the WRTRP were assessed. It was found that none of these associated facilities or activities induced a total effective dose in excess of the public radiation protection compliance criteria. The exception is areas very closure to the RTSF, with radon inhalation doses the most significant contributor to the total effective dose. This resulted in **no additional mitigation measures other than what is already proposed as part of air quality and groundwater specialist studies to be implemented to reduce the total effective dose to within compliance criteria**. Of particular note is the covering layer over the RTSF to facilitate revegetation, which will reduce the radon exhalation rate and thus the radon inhalation dose. However, it should be noted that the installation of a covering layer to reduce radon exhalation is very costly and may requires a more comprehensive cost-benefit analysis.

The following management actions were proposed:

- The revision and update of the RMP for the four Mining Right areas, including the revision and update of the public RPPs for the four CoRs (see Section 17.6).
- The completion of the baseline site characterisation studies of the potentially impacted areas before construction commence.
- Application of the necessary quality assurance and quality control measures during the construction phase.
- The application of land use restrictions in areas close to the RTSF, especially in the northern direction towards the Leeuspruit to reduce radon exposure.
- All historical TSF areas should be rehabilitated and cleaned to footprint level, after which the level of groundwater contamination beneath the site can be determined and appropriate mitigation measures proposed.
- All surface infrastructure, with the exception of the RTSF be decommissioned and the surface areas rehabilitated and cleaned to predetermined background levels as part of the decommissioning and closure phase.

17.6 Monitoring Plan

The NNR requires CoR holders to prepare and submit a public RPP as part of their licensing conditions, for approval. Presented here is recommendations for environmental monitoring for each Mining Right area for inclusion in the public RPP and ESMP. Each of the Mining Right area has an approved RPP for current conditions, and these recommendations for the WRTRP will thus be incorporated into the existing programmes.

17.6.1 Source Characterisation

The radiological impact assessment for the new facilities that are not yet operational such as the CPP, RTSF, and AWTF, were performed on a prospective basis. The source terms (i.e., what is released from these facilities into the environment) were therefore based on estimates rather that operational specific representative samples. For this reason, the monitoring programme should include a source characterisation programme comprising the following (once the facilities are operational):

- Quarterly sampling and full spectrum analysis of dust (PM_{10}) released from the CPP stacks, after which it can be decreased to one sample annually for total U and Th analysis to confirm operational conditions.
- Quarterly sampling and full spectrum analysis of tailings that will be deposited at the RTSF, after which it can be decreased to one sample annually for full spectrum analysis, to confirm operational conditions.
- Monthly representative sampling and full spectrum analysis of treated water from the AWTF before it is released to the Leeuspruit, after which it can be decreased to a biannual representative sample for full spectrum analysis to confirm operational conditions.
- Quarterly representative sampling and full spectrum analysis of RWD water before treatment at the AWTF, after which it can be decreased to an annual representative sample for full spectrum analysis to confirm operational conditions.
- Annual representative sampling and full spectrum analysis of tailings sample submitted from the various TSF to the CPP for processing, in other words of what is submitted to the CPP for processing to confirm operational conditions.
- Annual representative sampling and full spectrum analysis of uranium concentrate submitted to the Ezulwini processing plant to confirm operational conditions.
- Annual representative sampling and full spectrum analysis of tailings sample deposited at the Ezulwini North TSF to confirm operational conditions.

17.6.2 Cooke Mining Right Area

Apart from the thickeners and BWST, no new facilities and activities that may potentially release radioactivity to the environment is included in the WRTRP for the Cooke Mining Right area. The Cooke and Cooke 4 South TSFs are already monitored as part of the currently approved public RPP, and the recommendations would be to continue with the CoR-226 approved monitoring programme during the operational reclamation phase.

17.6.3 Ezulwini Mining Right Area

No new facilities and activities that may potentially release radioactivity to the environment is included in the WRTRP for the Ezulwini Mining Right area. The Ezulwini North TSF and the Ezulwini processing plant are already monitored as part of the currently approved public RPP, and the recommendations would be to continue with the CoR-58 approved monitoring programme during the operational phase.

17.6.4 Driefontein Mining Right Area

Apart from the West Block Thickeners and BWSF, no new facilities and activities that may potentially release radioactivity to the environment is included in the WRTRP for the Driefontein Mining Right area. The Driefontein No. 3 and Driefontein No. 5 TSFs are already monitored as part of the currently approved public RPP, and the recommendations would be to continue with the CoR-69 approved monitoring programme during the operational reclamation phase.

17.6.5 Kloof Mining Right Area

The Kloof Mining Right area include several facilities and activities not previously included in the Scope of CoR-70. For this reason, it is important to extent the currently approved public RPP to include facilities such as the CPP, RTSF and associated surface infrastructure (e.g. RWD and AWTF). It is assumed that by the time the facilities are commissioned, that the baseline site characterisation of the potentially affected areas are completed.

The CPP operates within a closed system, and no water is excepted to be released to the environment that requires monitoring. This means that it is only dust particles (PM_{10}) that will be released to the atmosphere *once the plant become operational*. The releases are expected to be very low, but once the activity concentration of what is released from the stacks are quantified (see Section 17.6.1), then PM_{10} samplers can be installed strategically to verify any potential contribution from the stacks. This should be done in collaboration with the air quality specialists to ensure the optimised location for the PM_{10} samplers. The PM_{10} filters can then be analysed for total uranium and total thorium. Due to the low activity concentration released from the stacks, full spectrum analysis is not required at this stage.

The RTSF is a large facility with potential releases to the atmosphere, groundwater and potentially to the surface water bodies in the area. The groundwater impact assessment specialist study proposed an extensive groundwater monitoring programme around the RTSF. It is proposed that a selected few of these boreholes around the facility be included for annual full spectrum analysis. The groundwater pathway is a very slow pathway and changes in the activity concentration of groundwater is not expected over the short term. After 5 years the full spectrum analysis can be reduced to total uranium and total thorium. Consistent with the groundwater specialist study, the following boreholes are proposed to be included (see Figure 17-1: SBNBH1, SBNBH3, SBNBH13, DM5, DM8, SBNBH12, SBNBH11, SBNBH10, SBNBH8, SBNBH5. These sampling locations may be altered pending the phased implementation of the RTSF.

The baseline site characterisation study includes the monitoring of environmental radon using RGM cups. Due to the dominant contribution of radon inhalation to the total effective dose, an environmental radon monitoring programme for the operational period is proposed. The monitoring programme should include the whole area around the RTSF. It is best to identify and optimise the monitoring points after construction of the RTSF for the following reasons:

- A phased implementation approach for the RTSF will be followed, which needs to be considered to ensure that the potentially affected areas are covered;
- The monitoring locations should include potentially affected areas, as well as potentially unaffected areas to establish variations in the radon air concentrations;
- Due consideration should be given to the results of the radon air dispersion modelling, which identified the area towards the northeast in the direction of the Doornpoort TSF as the main impacted area; and
- The recovery rate of RGMs tends to be low, due to theft. It is thus important to identify as secured locations as possible (e.g. at homesteads) for employment of the RGMs.

The RGMs are employed on a 3 month basis and should cover an two year period, after which the monitoring locations can be revised and updated given the outcome of the results. As subsequent phases of the RTSF are implemented, the monitoring programme should be revised to cover newly affected area.

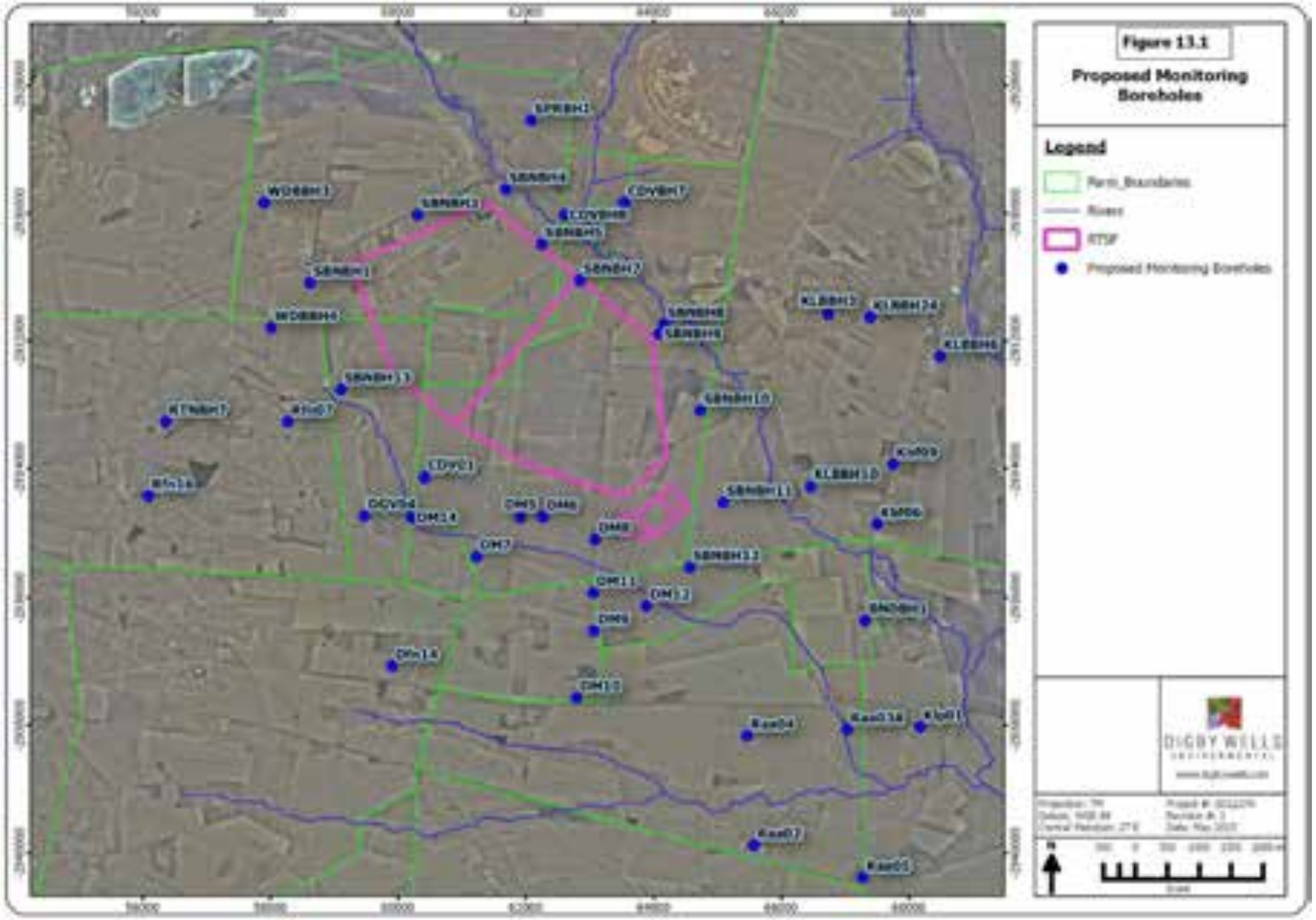

Figure 17-1: Boreholes around the RTSF identified for the groundwater monitoring programme (Digby Wells Environmental, 2015g).

With the exception of releases of treated water to the Leeuspruit, controlled or uncontrolled releases to the surface water bodies are not expected. The surface water pathway may be considered as an extension of the groundwater pathway, but due to the very slow migration rates, discharges to the nearby surface water streams through the groundwater pathway is not expected. However, the potential pollution of the nearby surface water bodies is a sensitive issue and it is consequently proposed that the surface water streams be monitored on a quarterly basis for full spectrum analysis on an upstream-downstream basis, and revised to annual full spectrum analysis after 2 years and quarterly analysis of total U and total Th.

18 Consultation Undertaken

Other than consultations with specialist performing the surface water, groundwater, atmospheric and socio-economic impact assessments for the WRTRP, no consultations were undertaken in compiling this report.

19 Comments and Responses

The comments received from stakeholders and the responses to these comments are listed in Table 20-1.

20 Conclusion and Recommendation

The report presented the radiological impact to members of the public induced by components and activities associated with the SGL WRTRP. The assessment of the radiological impact to members is based on the conditions and principles contained in Regulation 388 (April 2006) promulgated as safety standards by the NNR in terms of the NNRA (Act 47 of 1996). In terms of Regulation 388, the public dose limit, in terms of a total effective dose, is 1 mSv per annum, supported by a dose constraint of 0.25 mSv per annum.

The report provided a detailed description of the WRTRP, the potentially affected environment of relevance from a radiological perspective, as well as a summary of the baseline site characterisation study for potentially affected areas. Given that the purpose of these studies is to establish baseline conditions for post-operational rehabilitation, it was concluded that all sampling, surveys and analysis required for this purpose be completed before operations commence.

A systematic approach was followed for the purpose of the radiological impact assessment, which includes the derivation of public radiation exposure conditions to evaluate the radiological impact. Using a Source-Pathway-Receptor analysis approach, it was concluded that a Commercial Agricultural Exposure Conditions represents the most general and conservative conditions for use in the assessment. However, this does not mean that other exposure conditions might be suitable or applicable for the area or the WRTRP in general.

Table 20-1: Summary of the comments and response received on radiological issues.

Date of comments received	Method	Issues Raised	EAPs response to issues as mandated by the applicant
03-Feb-14	One-on-one Authorities Meeting	Current leaching is going on and there is existing pollution of soils. How will rezoning take place considering the half-life of the uranium?	Re-mining of the historic TSFs will remove these source of existing pollution. Being investigated to understand how much must be done to ensure closure. The RTSF footprint will be rezoned to special land use.
03-Feb-14	One-on-one Authorities Meeting	Is this similar to what is done by Mintails? Radioactivity is a concern because it remains well after reclamation and rehabilitation took place. The rehabilitated land might not be suitable for agriculture because it remains radioactive.	Similar to what is done at DRD Gold. Final rehabilitation of the reclaimed TSF footprint has to achieve standards set by the NNR for end land use. Working with specialists to cut into surface and take out radioactive material to understand feasibility at this stage.
02-Dec-14	One-on-one Authorities Meeting	A radiation protection function needs to be integrated as part of the EIA and associated processes.	The EIA process as well as a public and worker assessment is required to be carried out for approval of the NNR which will require monitoring and reporting. Sibanye have a dedicated radiation protection team that will work on the WRTRP.
02-Dec-14	One-on-one Authorities Meeting	Will there be an opportunity to separate the various active materials when taken out of the tailings?	Information on this will become available once the full spectrum analysis has been done which can be investigated.
02-Dec-14	One-on-one Authorities Meeting	Will applications be done for the different CORs?	Yes, for each area and CORs amendments will be done.
21-Apr-15	NGOs Focus Group Meeting	The occurrence of radiation in the process of making and using bricks from waste rock dumps is a high risk. Certain activities that involve waste products associated with aforementioned are outside of NNR regulations and can therefore not the licensed.	Thank you for the comment.

Date of comments received	Method	Issues Raised	EAPs response to issues as mandated by the applicant
21-Apr-15	NGOs Focus Group Meeting	This is on behalf of affected communities as there are already affected communities, how are you going to re-mine the tailings dumps? What about the radiation where communities located in close proximity of the TSFs to be reclaimed? Which mitigation strategies are you going to use to reduce the radiation levels? The Westrand already has high level of radiation.	The remaining footprint after reclamation is the biggest challenge, but the needed closure and rehabilitation plans will be developed in collaboration with the relevant competent authorities. This will also include end land use which will be considered as part of the social studies to be undertaken. One of the reasons the project is being undertaken is to remove the latent radiation found in these tailings facilities. This will reduce the risk and exposure for communities. NNR approvals for the project require assessments to be done for workers and public in and around the TSFs to be reclaimed.
28-Apr-15	Written Comment	Radiometric surveys over previously reprocessed mine residue deposit footprints have, in some cases, shown elevated levels of residual radioactivity in soils. In these cases, it must be accepted that some areas will never be suitable for unrestricted development and that these areas will need to be demarcated as such, and appropriated land-uses proposed and implemented.	Thank you. This is a valuable comment and will definitely be taken into account. It is understood that the land use can only be determined once the historical TSFs are removed. The radioactive material and impact on the underlying soils will vary for each footprint, therefore the end land use potentials will be different.
06-Oct-15	Written Comment	Farm is already unsustainable for agriculture caused by radioactive substances and heavy metal and salt content in water. Destruction of wetland area, killing animals (fish and even trees and other vegetation rendering the farm useless.)	A radiological specialist study will be undertaken to determine environmental impacts and the results thereof, together with mitigation measures, will be available to stakeholders during the Impact Assessment phase.
07-Oct-15	Open House	Concerned about the environment because of Uranium; for the future and also care for people who must be protected.	A radiological specialist study will be undertaken to determine environmental impacts and the results thereof, together with mitigation measures, will be available to stakeholders during the Impact Assessment phase.
07-Oct-15	Open House	What is the impact of Uranium on people?	A radiological specialist study will be undertaken to determine environmental impacts and the results thereof, together with mitigation measures, will be available to stakeholders during the Impact Assessment phase.

Date of comments received	Method	Issues Raised	EAPs response to issues as mandated by the applicant
13-Oct-15	NGOs Focus Group Meeting	Radioactivity in soils must not to exceed 500 Bq/kg - the risk of radioactivity transferal always exists e.g. from cattle to milk to meat and also via other pathways. Will all the pathways be investigated?	Yes. This will be addressed in the radiological Public Safety Assessment which forms of the NNR licencing process.
13-Oct-15	NGOs Focus Group Meeting	Exposure is at 1mSv and the regulated standard is 250 microSieverts (uSv) - this must be measured per source, and not more than 4 sources. Chronic exposure must also be investigated.	Noted. This will be addressed specifically in the cumulative aspect of the radiological Public Safety Assessment which forms of the NNR licencing process.
13-Oct-15	NGOs Focus Group Meeting	The chronic exposure to uranium has been seen in research to have a negative impact on health.	Thank you for the comment.
13-Oct-15	NGOs Focus Group Meeting	Prof Frank Winde found through research that the use of water for mining introduces air into the tailings, which can cause AMD. The use of impacted water introduces air or water aerobic contamination, as shown in recent studies, which may cause AMD on the short term.	Thank you for the comment.
13-Oct-15	NGOs Focus Group Meeting	Resource Quality Objectives needs to be clearly defined and stated upfront since there are various rivers in the area that are highly used. Considering this, numerical limits must take into account radiological or Uranium where 15mg/l is the limit.	Thank you for the comment.
22-Oct-15	Written Comment	Recognise that reprocessed mine residue deposit footprints may have, in some cases, elevated levels of residual radioactivity in the soils. In these cases, it must be accepted that some areas will never be suitable for unrestricted development and that these areas will need to be demarcated as such, and appropriate land-uses proposed and implemented.	Your comment is noted.

Date of comments received	Method	Issues Raised	EAPs response to issues as mandated by the applicant
4-Nov-15	Written Comment	The FSE recommends that an assessment of all pathways, including the risks posed by the inhalation and ingestion of radioactive dust and the deposition of crops, as well as the pathway sediment→SPM →cattle→milk/meat→person (“SeCa”) be conducted. It was found by the NNR-Report that the SeCa pathway can cause radioactive contamination of livestock products (milk, meat) resulting in effective doses of the public in some orders of magnitude above those resulting via the pathway “WaCa.	The radiological specialist will be alerted to your comments in this regard.
4-Nov-15	Written Comment	The FSE recommends that the risks pertaining to radon, stay on or in close proximity to contaminated land and/or unauthorised entry to mine sites be investigated and mitigation measures proposed.	This is an important aspect to consider with respect to land use. Appropriate mitigation measures will be provided within the soils report and the rehabilitation plan, as the level of contamination will determine the potential land use and what remedial action is required.

Date of comments received	Method	Issues Raised	EAPs response to issues as mandated by the applicant
4-Nov-15	Written Comment	The study confirmed the results for uranium of Wade et al. (2002), with uranium concentrations of several hundred mg/kg being found in the sediment (the expected natural background concentration for a dolomitic area such as this would be less than 1 mg/kg). The study also identified a number of other heavy metals of concern, and noted that these appeared to follow the same behaviour as the radionuclides described by Wade et al. (2002). Based on laboratory studies and chemical modelling, the metals (uranium-series radionuclides are all metals, and behave chemically as such in the environment) are adsorbed or chemisorbed to a number of sediment phases, all of which can be re-released by plausible geochemical processes. These two studies on sediment concluded that while current conditions were relatively stable, albeit not totally effective in removing metals from the water, the unpredictability of the future required management plans that would either maintain conditions as they were ad infinitum or would have to contemplate rehabilitation of the contaminated areas within the environment. The most important lesson learnt from the studies in the Wonderfonteinspruit is that no short-cuts exist which would allow certain pathways to be ignored in a study of radioactive contamination within these mining areas.	Unfortunately this project can not be burdened with the legacy issues associated with mining in the general area over the last 130 years.

The impact assessment included an evaluation of the groundwater pathway on a *System Level Model* basis. It was concluded that although the groundwater pathway is an always will be a sensitive pathway, its potential contribution to a total effective dose during especially the operational period, but also the post-operational period, is limited mainly due to the timescales of concern of the development and subsequent migration of a contaminant plume to receptor locations. It was further illustrated that for the RTSF, a radionuclide contaminant plume will not reach a borehole 300 m downgradient within hundreds of thousands of years post-closure. This is mainly due to the nuclide specific retardation properties of the tailings material, the unsaturated zone and the saturated zone. This means that the contaminant plume is mainly being contained at the RTSF facility itself.

The contribution from the atmospheric pathway is more significant, with radon inhalation the main contributor. The area of impact from releases of particulate matter is towards the southwest, whereas the radon dispersion is towards the northeast towards the Gold Fields Doornpoort TSF. The highest impact is close to the RTSF, but decrease significantly with distance away from the facility. Within a few hundred metres from the RTSF, the total effective dose decreases to below the dose constraint of 0.25 mSv per annum. The cumulative impact with the Doornpoort TSF is thus expected to be still within the compliance criteria for public exposure.

The contribution from the CPP to a total effective dose is very low, with dust inhalation the only contributor from the particulate matter released from the various stacks. The total effective dose, even in close proximity of the CPP, is not expected to reach the dose constraint of 0.25 mSv per annum.

The total effective dose induced by treated water from the AWTF is very low. Provided that the treatment levels to remove contaminants from the RWD water can be maintained, it is unlikely the total effective dose will reach the dose constraint of 0.25 mSv per annum.

The total effective dose in the vicinity of the reclamation operations associated with the Driefontein and Cooke Operations is not expected to be different from current (pre-operational) conditions. However, the benefit during the post-operational period is significant, because of the removal of the TSF as source and thus the total effective dose contribution. For members of the public to experience this benefit, it is essential that the reclamation area be rehabilitated completely down the footprint level. It was also noted that the groundwater beneath the TSF will be contaminated, but the level of contamination and the remedial measures that might be required can only be determined once the footprint level is reached. Only then would it be possible to determine the final land use conditions.

With the dose assessment for the different components and facilities associated with the WRTRP as basis, the radiological impact assessment ratings were determined. It was concluded that most activities and facilities has a **Low to Medium Low (Negative)** during the operational and post-operational phases. Radiological material is not handled during the construction phase, and therefore the radiological impact is not of concern. The exception is the reclamation of the historical TSFs, which resulted in a **Moderate (Positive)** impact rating, mainly because of the positive contribution to the total effective dose if the sources (TSFs) are removed.

It was concluded that remedial actions as part of the EMP and public RPP are generally not required to reduce the radiological impact. The exception is the RTSF, which may include the application of a covering layer as part of the revegetation processes, which will be implication reduce the radon exhalation rate and thus the radon inhalation dose. However, this measure did not influence the impact rating. Note that most of the mitigation measures proposed as part of the air quality or groundwater impact assessment studies will have an indirect influence on the radiological impact, resulting in a potential decrease in the total effective dose. Several additional management actions were proposed for inclusion in the EMP and RPP. The proposed monitoring programme focused on source characterisation once the WRTRP is operational, as well as environmental monitoring of various environmental media.

Viewed from a radiological impact perspective, both in terms of the total effective dose calculations and the associated impact assessment ratings, it is recommended that the WRTRP goes ahead as proposed, subject to the conditions:

- That the baseline site characterisation studies be completed before commissioning of the associated WRTRP activities
- That the different components of the project are implemented with due consideration of the quality control and quality assurance as outlined in the design of the different components;
- That the historical TSFs be rehabilitated down to footprint level and according to the final land use conditions foreseen for the specific area; and
- That the recommendations for inclusion in the EMP and public RPP be carried out, including the source term characterisation and monitoring recommendations.

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Appendix A: Appendix Title

Appendix B: Appendix Title