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Content

1. Introduction

International operational experience at nuclear power stations has shown that groundwater contamination occurs from a variety of sources and is due to various causes. For example, the US nuclear industry has subsequently undertaken a Groundwater Protection Initiative at the direction of the NSIAC, and in response to industry best practice, KNPS developed this site-specific Groundwater Protection Programme.

There is currently no pathway from any possible on-site contaminated groundwater to the public given that the plant groundwater is encapsulated (plant boundary sub-surface cut-off wall and Malmesbury aquifer upwelling) and the direction of the groundwater flow is towards the sea. The intent of the GPPRM is to establish prevention and mitigation measures for groundwater protection which includes early detection of groundwater contamination with the ultimate objective to ensure that groundwater contaminant levels are within acceptable levels due to the following reasons:

- To ensure environmental duty of care (Section 19 of [1] and Section 28 of [2]) which requires the prevention and/or minimisation and remediation for past, current or future groundwater pollution and to address any potential public concern issues.
- To avoid unacceptable radionuclide and non-radioactive contamination levels should the public use the groundwater after the land is released after plant decommissioning.

2. Supporting Clauses

2.1 Scope

2.1.1 Purpose

This manual specifies the requirements for groundwater protection at KNPS. It includes monitoring, prevention and mitigation measures to ensure that groundwater contaminant levels, from above ground and below ground leaks and spills from radioactive and non-radioactive contaminants, are within acceptable levels.

2.1.2 Applicability

This document shall apply to groundwater protection activities at KNPS.

2.1.3 Effective date

This document is effective from the date of authorisation. It should be noted that the programme is established in a phased approach as discussed in §3.2.

2.2 Normative/Informative References

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] National Water Act (No. 36 of 1998)

[2] National Environmental Management Act (No. 107 of 1998)

[3] 331-148, “Programme Engineer’s Guide”

[4] 240-85697643, “Groundwater Governance Guideline”

[5] Water Permit 853N and Exemption 1133B, 1985

[6] 238-47, “Radiological Environmental Surveillance Requirements”

[7] Advisian Worley Parsons Group, C00359-1, “Koeberg Groundwater Monitoring, Geohydrology Study and Groundwater Modelling”, May 2016

[8] Nuclear Support, Nuclear Environmental, NSC-004-19, “Radiological Criteria for Site Ground Water Monitoring”

[9] SANS 241:2015, “South African National Standard, Drinking water”

[10] General Notice, Notice 169 of 2013, “Department of Water Affairs, Revisions of General Authorisations in Terms of Section 39 of the National Water Act, 1998 (Act No. 36 of 1998)”

[11] US EPA, EPA 816-F-09-004, “National Primary Drinking Water Regulations”, May 2009

[12] Advisian Worley Parsons Group, C00278, “Koeberg Nuclear Power Station, Site Contamination Assessment Phase 1”, March 2019

[13] Ninham Shand Consulting Services Cape Town, Drawing No 403211 CT4, “Koeberg Wastewater Treatment Survey, General Layout and Keyplan, Sewers and Stormwater”

[14] Robert W. Puls and Michael J. Barcelona, “EPA Ground Water Issue, Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures”, United States Environmental Protection Agency, Office of Research and Development, Office of Solid Waste and Emergency Response, EPA/540/S-95/504, April 1996

[15] Department of Minerals and Energy, “Safety Standards and Regulatory Practices, Regulations 388 in terms of the National Nuclear Regular Act 47 of 1999, GG 28755 of 28 April 2006”

[16] KLA-005, “Koeberg Event Classification and Reporting Criteria Listing”

[17] 331-3, “Nuclear Engineering Documentation and Records Management Work Instruction”

2.2.2 Informative

[18] National Environmental Management: Waste Act (No.59, 2008)

[19] Department of Water Affairs and Forestry, 2008. Policy and Strategy for Groundwater Quality Management in South Africa

[20] Department of Water Affairs and Forestry, 1998. Minimum Requirements for Water Monitoring at Waste Management Facilities

[21] EPRI, 2013. Groundwater Protection Guidelines for Nuclear Power Plants Rev1: Palo Alto, CA: 3002000546

[22] Institute of Nuclear Power Operators (INPO), 2010, Review of Sources of Unexpected Tritium Releases to the Environment, Topical Report TR 10-71

[23] Nuclear Energy Institute, 2010, Guideline for the Management of Underground Piping and Tank Integrity, NEI 09-14 Rev 1

PAIA section 36(b). Redacted as it contains 3rd party references

2.3 Definitions

2.3.1 **Acceptance criteria:** The standard against which test results are to be compared.

2.3.2 **Aquifer:** A geological formation that has structures or textures that hold water or permit appreciable water movement. Also defined as the saturated zone of a geological formation beneath the water table, capable of supplying economic and usable volumes of groundwater to borehole(s) and / or springs.

2.3.3 **Borehole:** Includes an excavation or any other artificially constructed or improved underground cavity that can be used for the purpose of intercepting; collecting or storing water in, or removing water from an aquifer; for observing and collecting data and information on water in an aquifer or; for recharging an aquifer. Also a well point or a piezometer for use in monitoring purposes.

2.3.4 **Confined aquifer:** An aquifer which is overlain by a confining layer of significantly lower hydraulic conductivity. The groundwater is confined under pressure greater than atmospheric pressure such that if the aquifer is penetrated, the water level may rise above the top of the aquifer. Also known as an artesian aquifer.

2.3.5 **Contamination:** The introduction into the environment of any substance by the action of man.

2.3.6 **Ephemeral:** Refers to watercourses that are generally storm-driven and in which flow occurs less than 20 % of the time; these watercourses have a limited (if any) base flow component with no groundwater discharge.

2.3.7 **Groundwater:** Water found in the sub-surface in the saturated zone below the water table.

2.3.8 **Hydraulic conductivity:** Measure of the ease with which water will pass through porous material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (m/d).

2.3.9 **Hydraulic gradient:** Change in hydraulic head per unit of horizontal distance in a given direction, i.e. the difference in hydraulic head divided by the distance along the groundwater flow path. Groundwater flows from points of high elevation and pressure to points of low elevation and pressure.

2.3.10 **Hydrocensus:** A survey of an area to gather information on water features, water supply sources and sources of potential water pollution. Used in this report more specifically to refer to a detailed survey of groundwater wells and their characteristics (location, depth, yield and water quality).

2.3.11 **Hydrogeology:** The area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the Earth's crust. The terms groundwater hydrology, geohydrology, and hydrogeology are often used interchangeably.

2.3.12 **Ionising radiation:** Radiation that carries sufficient energy to detach electrons from atoms or molecules.

2.3.13 **Major aquifer system:** Highly permeable formations, usually with a known or probable presence of significant fracturing, may be highly productive and able to support large abstractions of water for public supply and other purposes; water quality is generally very good.

2.3.14 **Piezometer:** A well designed to measure the elevation of the water table of groundwater.

2.3.15 **Radionuclide:** An atom that has excess nuclear energy making it unstable and consequently emits ionising radiation to gain stability.

2.3.16 **Saturated zone:** The sub-surface zone below the water table where interstices (large and small voids) are filled with water under pressure greater than that of the atmosphere.

2.3.17 **Semi-confined aquifer:** An aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur; also referred to as a leaky aquifer.

2.3.18 **Shall, Should, May:** The word “shall” is used to denote a requirement; the word “should” to denote a recommendation and the word “may” to denote permission i.e. neither a requirement nor a recommendation.

2.3.19 **Sole source aquifer:** An aquifer that is needed to supply 50 % or more of the domestic water for a given area, and for which there are no reasonably available alternative water sources should the aquifer be impacted upon or depleted.

2.3.20 **Water table:** The upper surface of groundwater systems.

2.3.21 **Well point:** A shallow, small diameter borehole used to abstract groundwater from a primary aquifer.

2.4 Abbreviations

Abbreviation	Explanation
ALARA	As Low As Reasonably Achievable
ATE	Condensate Polishing Plant System
BNI	Balance of Nuclear Island
CAS	Central Alarm Station
CoCT	City of Cape Town
COD	Chemical Oxygen Demand
CSM	Conceptual Site Model
CTE	Circulating Water Treatment System
DL	Inverter
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DRM	Documentation and Records Management
DRO	Diesel Range Organics
DSSR	Duynefontein Site Safety Report
DVN	Nuclear Auxiliary Building Ventilation System
DWS	Department of Water and Sanitation
EMS	Environmental Management System
ESL	Environmental Surveillance Laboratory

Abbreviation	Explanation
EU	European Union
GCT	Turbine Bypass System
GEX	Generator Excitation System
GPPRM	Groundwater Protection Programme Requirements Manual
GRIP	Groundwater Resources Information Project
GRO	Gasoline Range Organics
GRU	Groundwater Resource Unit
KNPS	Koeberg Nuclear Power Station
KER	Monitoring and Discharge of Nuclear Island Liquid Radwaste (BNI System)
MAP	Mean Annual Precipitation
MCGL	Maximum Contaminant Goal Level
MCL	Maximum Contaminant Level
MDA	Minimum Detectable Activity
NNR	National Nuclear Regulator
NSIAC	Nuclear Strategic Issues Advisory Committee
PAC	Polycyclic Aromatic Compounds
PAH	Polycyclic Aromatic Hydrocarbons
PBMR DPP	Pebble Bed Modular Reactor Demonstration Power Plant
PCB	Polychlorinated Biphenyls
PVC	Polyvinyl Chloride
RP	Radiation Protection
SACNASP	South African Council for Natural Scientific Professions
SANAS	South African National Accreditation System
SEO	Rain Water Drainage System
SEU	Plant Sewer System
SSC	220V AC Essential Supply Board 1
SSD	220V AC Essential Supply Board 2
TPH	Total Petroleum Hydrocarbons
TR	Power Transformer
TX	Steam Transformer
US	United States
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
WARMS	Water Allocation Resources Management System
WHO	World Health Organisation
WMA	Water Management Area
WUL	Water Use License
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Units	Explanation
Bq/l	Becquerel per Litre
EC	Electrical Conductivity (mS/m)
l/s	Litres per Second
mamsl	Meters Above Mean Sea Level
mbgl	Meters Below Ground Level
m^3/a, Mm^3/a	Cubic Meters per Annum, Million Cubic Meters per Annum
m/d	Meters per Day
mg/L	Milligrams per Litre
mS/m	Millisiemens per Meter
mSv/y	Millisieverts pr Year
NTU	Nephelometric Turbidity Unit
Ppm	Parts per Million
pH	Acidic/Basic Nature of Water
Pt-Co	Platinum-Cobalt Colour Scale
TDS	Total Dissolved Solids (mg/L)
TU	Tritium Units
µg/L	Micrograms per Litre

2.5 Roles and Responsibilities

2.5.1 The Programmes Engineering Manager is responsible for implementing this manual.

2.5.2 The Programme Owner is the custodian of this manual and is responsible for ensuring that the requirements are met, that the manual is updated accordingly to reflect changes in the requirements and that it is periodically reviewed to ensure effectiveness.

2.5.3 The Programme Owner is responsible for ensuring that a strategy is developed for sampling the groundwater and soil and; interpreting the results.

2.6 Process for Monitoring

The Programme Owner will use guidance provided by [3] and [4] for managing this programme. The process which is based on [4] is described in Appendix A.

2.7 Related/Supporting Documents

Not applicable.

3. Programme Requirements

3.1 Basis

The programme framework is based on the Eskom groundwater governance guidelines [4]. The current water permit/exemption for KNPS [5] which falls under the National Water Act of 1998 [1] deals predominantly with the use and discharge of surface water from the plant and does not specifically require any groundwater monitoring. The site groundwater monitoring programme will not form part of the ESL Programme [6] since the ground water on site is not used for drinking water and as such is not a dose pathway. However the ESL Programme radiological monitoring requirements [6] will be used as guidance for this programme until a better basis is found.

To have an effective programme, groundwater flow needs to be understood to determine sampling point locations and depths; borehole designs; sampling methods, frequency and constituents; risk assessments and; corrective actions including prevention, mitigation and (if necessary) remediation measures. Groundwater flow at and around KNPS is based on hydrogeology and groundwater modelling [7]. Groundwater modelling and risk assessments should be updated (as deemed necessary) when new data is obtained as the programme progresses.

Acceptance criteria for radionuclides are based on the KNPS environmental position [8]. Acceptance criteria for non-radioactive substances are based on the drinking water standard [9], statutory general authorisation [10] and the US EPA drinking water regulations [11]. Currently there are no requirements in terms of decommissioning as there is no decommissioning plan.

3.2 Programme Establishment

The programme is established based on the process in Appendix A [4]. The guideline references in Appendix A Table 1 are described in [4]. The programme is established in a phased approach as the output from one phase is the input into the subsequent phase. The phases are described below.

3.2.1 Phase 1

Phase 1 includes 2 parts.

3.2.1.1 Part 1

A study was conducted [7] which determined and developed respectively, the site hydrogeology; the groundwater conceptual site and numerical models and; the adequacy of the existing groundwater monitoring network.

3.2.1.2 Part 2

A site contamination assessment was conducted [12] building on the findings and recommendations of Phase 1 Part 1. This assessment determined the new borehole locations and design; the soil and groundwater sampling scope; the sampling methodology and; the refurbishment scope for the existing boreholes.

3.2.2 Phase 2

New boreholes will be constructed to establish an early warning system for future contamination events and to identify historical pollution events. The soil removed from drilling and the borehole's groundwater will be sampled and analysed to establish a baseline. Baseline results of contaminants will determine the need for additional boreholes and historical contamination levels. Groundwater modelling and risk assessments should be updated (as deemed necessary). The existing boreholes will be refurbished in this phase or Phase 3.

3.2.3 Phase 3

Additional boreholes will be constructed to determine the contamination plume or extent of contamination. As in Phase 2, the soil removed from drilling and the borehole's groundwater will be sampled and analysed. Ongoing periodic monitoring will be performed till the plant is decommissioned. Groundwater modelling and risk assessments should be updated as deemed necessary.

3.2.4 Phase 4

This phase includes the decommissioning scope as advised by (but not limited to) this programme and the KNPS decommissioning requirements.

3.3 Risk Assessment

3.3.1 General

Groundwater risk assessment entails the understanding of the groundwater hazard, the probability that the hazard will occur and the consequences if it should occur, i.e. understanding of the complete cause-and-effect cycle. The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates and finally the target that experiences the risk (receptor). The risk-assessment approach is therefore aimed at describing and defining the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

The first and most critical component of a risk and impact assessment is the development of a suitably detailed conceptual site model. The CSM is arguably the most important step in the whole risk assessment exercise, as it defines the questions that need to be asked, the design of the sampling programme, the tools and techniques to be applied in the prediction and the various assumptions and data values that will be used in the risk assessment [4].

3.3.2 Conceptual Site Model

The CSM is discussed in §3.5.1.

3.3.3 Quantitative Risk Assessment

A quantitative risk assessment is technically very complex and should be conducted by a SACNASP registered hydrogeologist and according to the guidelines in [4]. The CSM will help to define the sources of potential impact and the pathways for groundwater impact and receptor or receptor areas. The level of complexity of the risk assessment should be appropriate to both the objectives of the site, its characteristics and available data.

Eskom requires that a quantitative risk assessment be performed in the following circumstances:

- Where ecosystem protection is the principal objective and harm to a water resource/ecosystem may occur.
- The beneficial uses of the groundwater are for a potable water supply and harm to a water user may occur.

3.3.3.1 Quantitative Risk Assessment Frequency

The following quantitative risk assessment frequencies are proposed for Eskom's operations:

- For existing operations, reviewed every second year during operation.
- Before decommissioned operations are recommissioned.
- When knowledge is obtained regarding new critical receptors.
- When deemed necessary following review of operating experience.
- When new waste facilities are built, waste facilities expanded, contamination is observed through unidentified leakages, large-scale dewatering takes place or when contamination sources are newly delineated. At KNPS, the dry spent fuel storage casks are considered new waste facilities.

3.4 Site Details

The intent of this section is to support assessments, analyses and data interpretation. The information in this section is obtained from historical sources from [7].

3.4.1 General

KNPS is located along the West Coast, approximately 30 km north of Cape Town and within the municipal boundaries of the CoCT Metropolitan Municipality. The location is shown in Appendix B Figure 2. Access to KNPS is via the R27 or Otto du Plessis Drive. The suburbs of Duynefontein and Melkbosstrand are located approximately 0,7 km and 2,2 km south of the site, respectively, while the industrial and residential town of Atlantis is located approximately 10 km northeast of the site.

KNPS falls within quaternary catchment G21B and in the Berg-Olifants WMA. The quaternary catchment has been subdivided into eight GRUs based mainly on geology, surface drainage features, the bedrock topography and groundwater flow regime in the unconsolidated Cenozoic-age deposits. KNPS falls within the Duynefontein GRU (Unit H).

The Duynefontein GRU extends from the edge of the Atlantis industrial area southwards to the Sout River near Van Riebeeckstrand. The western and eastern boundaries of the GRU are formed by the coastline and outcrops of the Tygerberg Formation rocks (Malmesbury Group), respectively. The GRU is predominantly covered by geologically younger sediments of the Witzand and Springfontein Formations.

The topography from inland (east) of KNPS is relatively flat with a gentle slope towards the coast. However, both ancient dunes stabilised by vegetation and Recent-age unconsolidated dunes with heights of < 10 m are found north of KNPS along the coastline. South of KNPS, the land is relatively flat with a few low-lying dunes close to the coast.

No river channels or permanent runoff channels drain the immediate site. The Sout and Diep rivers drain the broader areas within the study area (20 km radius around the site). The Donkergat River, a tributary of the Sout River, occurs east of the site and joins the Sout River south of KNPS near Melkbosstrand. The rivers all flow in a south-westerly direction towards the coast. The tributaries are generally ephemeral in nature and only flow for short periods after significant rainfall events. Based on the nature of these rivers, it is suggested that groundwater does not discharge into the rivers (i.e. no base flow component). Most of the smaller streams 'disappear' in the flat sandy areas near the ocean and cannot maintain open river channels across the narrow raised dunes along the coast.

Regionally, groundwater in the vicinity of KNPS is used for brickmaking and sand mining. Groundwater is also used for small-scale vegetable farming, water for horses and irrigation of commercial lawn. Though a reticulated municipal water pipeline was made available to most smallholdings during 2002, many users still utilise groundwater and it is the preferred choice for water supply due to the high cost of municipal water.

The majority of the erven in Duynefontein to the south of KNPS have well points used for garden irrigation purposes with an estimated 173 000 m^3/a of groundwater being abstracted. The January 2008 DSSR hydrocensus determined that around 30 000 m^3/a of groundwater is abstracted from four boreholes along the Aquarius wellfield (GCS1, GCS7, GCS9 and GCS10). The groundwater from these boreholes is currently used for stock watering and irrigation purposes, as well as to supply the dam at the KNPS conservation offices. These boreholes were initially drilled to supply water to KNPS but showed high salinity and variable quality. The cost of desalination at the time was deemed prohibitive therefore use is limited to filling the dams and for fire prevention.

Boreholes within the Sandveld aquifer surrounding KNPS yield between 0,5 – 5 l/s. Two boreholes that were drilled in 1991 during a water supply investigation along the northern boundary of KNPS yielded 1,7 and 4,2 l/s. Other boreholes drilled during various investigations to the north of KNPS yielded 2 – 6 l/s and the boreholes in the Sandveld aquifer drilled for the DSSR showed yields of 5,1 – 7 l/s.

The Atlantis Aquifer is a highly productive aquifer > 5 km north of KNPS and shows borehole yields of > 10 l/s from production boreholes in the Witzand and Silwerstroom Wellfields. Atlantis is largely dependent on groundwater for its water supply. Groundwater is abstracted from 40 boreholes and used for domestic and industrial purposes. Based on modelling results, the sustainable fresh water yield of the Witzand Wellfield is 5,8 Mm^3/a. CoCT data indicates 2,6 Mm^3/a of groundwater was abstracted from the two wellfields in 2007, significantly less than what was estimated during 1998/1999. There are no visible signs of any negative impacts caused by groundwater abstraction from the Atlantis Aquifer, and the Silwerstroom spring is still flowing in spite of continued groundwater abstraction from the Silwerstroom Wellfield. Recently artificial recharge to groundwater has further eased the impact of abstraction from this aquifer. The Atlantis Aquifer is fully allocated and no further development or increased abstraction (other than rehabilitating the existing boreholes) will be allowed.

No large scale abstraction occurs from the Malmesbury aquifer and only small scale abstraction occurs in farming areas north of KNPS. Groundwater is used for irrigation primarily due to the variable quality and saline nature of groundwater in this aquifer. Yields from this aquifer tend to be low, in the order of < 0,5 l/s, but along extensive fractures the yields can be much higher (> 5 l/s). The variation in groundwater quality (10 – 1000 mS/m) is due to the highly variable lithology with variable thicknesses and the extent of mudstone, siltstone, greywacke, phyllitic shale, siltstone and quartzite layers. Boreholes drilled into the

Malmesbury aquifer at the planned CoCT regional landfill facility south of Atlantis yielded 0,1 – 0,3 l/s. At the PBMR site, six boreholes drilled into the Malmesbury aquifer showed blow yields of 2 – 12 l/s, with a mean yield of 5 l/s. These high yields encountered in the Malmesbury aquifer are uncommon but possible in extensive fracture zones.

3.4.2 Construction and Layout

The bentonite cement cut-off wall was constructed in 1976 around the KNPS excavation during construction of the foundations. This was done prior to dewatering of the excavation, which commenced in January 1977 with construction of the nuclear raft. This cut-off wall extended to bedrock to protect the excavation from ground and sea water ingress during construction.

The excavation removed weathered material and excavated down to hard, unweathered bedrock. It was noted that the bedrock was intensely fractured which opened many of the discontinuities and groundwater constantly seeped into the base of the excavation from the Malmesbury bedrock. This seepage is as a result of the removal of the 5 m of weathered clay material generally present above the Malmesbury aquifer. This weathered layer generally acts as a barrier to groundwater flow between the Malmesbury and overlying Sandveld aquifers.

Grouting of seepage/open fractures was too costly. Therefore dewatering surrounding the site was performed as well as collection of groundwater in sumps and continual pumping of water that collected in the excavation. The inferred location of the cut-off wall is shown in Appendix B Figure 3. Based on interpretation of historical site plans the following dimensions of the cut-off wall have been determined.

- The top of the cut-off wall is 3 m below the current ground surface of the nuclear raft area. This corresponds to -3 mbgl and 5 mamsl.
- The wall extends to 19 – 20 m below the current ground surface (on average 11 m below sea level).
- The wall is 300 m in length along the eastern and western portions and 250 m in length along the northern and southern portions.
- The wall is estimated to be 0,4 – 0,7 m thick and on average 0,5 m thick.
- The location of the cut-off wall relative to the nuclear island and turbine hall: 45 – 54 m from the eastern edge of the raft, 56 – 70 m from the northern edge, 52 – 66 m from the southern edge and 41 – 51 m from the western edge.
- The bentonite-cement wall is considered impermeable to groundwater seepage.
- The area between the cut-off wall and the nuclear island and turbine hall was backfilled and predominantly covered with tarmac. A few grassed/open areas occur along the northwest and western inner extent of the cut-off wall with open gravel around borehole TW5.
- The sea-side (western) cut-off wall, at the time of construction, was 150 m from the shore and the area between the cut-off wall and the seawater intake and pumping station is partially covered with tarmac and partially grassed.
- The backfill material between the nuclear island and turbine hall and the cut-off wall is compacted sand from the Sandveld aquifer which was removed from the excavation during construction.

- The nature of the backfill material is not well-known but it is presumed that it consists of a compacted Sandveld sand, silt, clay and carbonate and; that it excludes weathered Malmesbury group clay, silt and rubble.

Ground or terrace elevation surrounding the nuclear island and turbine hall is levelled at ±8 mamsl and is predominantly covered in tarmac. The tarmac forms a road completely surrounding the nuclear island and turbine hall buildings. Below-ground structures on site are shown in Appendix B Figure 4.

3.4.3 Hydrogeology

3.4.3.1 Aquifer Types, Classification and Vulnerability

Groundwater in and around KNPS occurs in two aquifers described below. The aquifer types are shown in Appendix B Figures 5 – 6 and Appendix C Figures 7 – 12.

- The upper unconfined primary (intergranular) Sandveld aquifer.
- A deeper semi-confined secondary fractured Malmesbury Group bedrock aquifer.

The Sandveld aquifer is an important and significant primary aquifer a subset of which forms the Atlantis Aquifer with two wellfields (Witzand and Silwerstroom) situated > 5 km north of KNPS. These wellfields supply water to the surrounding towns (predominantly to Atlantis) and comprise numerous boreholes which occur north and north east of KNPS.

The Malmesbury fractured rock aquifer shows highly variable groundwater quality and quantity across the site and regionally. Due to the highly deformed, fractured and variable thicknesses and the extent of the numerous lithologies (mudstone, siltstone, greywacke, phyllitic shale, siltstone and quartzite), groundwater flow and yield vary considerably. Due to the highly fractured nature of the Malmesbury aquifer, groundwater leakage into overlying aquifers is common, thus the semi-confined nature of this aquifer. In areas where a thick weathered clay layer has formed above the Malmesbury aquifer, up to 5 – 6 m thick, the Malmesbury aquifer shows a confined nature and no groundwater exchange occurs. Where this weathered layer has been removed, upwelling of the Malmesbury aquifer will occur as occurs under KNPS.

The Atlantis part of the Sandveld aquifer is classified as a Sole Source aquifer system. Some smallholdings to the south of KNPS are dependent on groundwater. Although a reticulated pipeline for supply was constructed during 2002, the high cost of municipal water results in these small holdings using groundwater. The primary aquifer system towards the east of the site is classified as a Major Aquifer system with high vulnerability to anthropogenic impacts. The primary aquifer's vulnerability is mainly due to its shallow unconfined water table and high permeability.

The Sandveld aquifer surrounding the KNPS site similarly has a high vulnerability. The aquifer underlying the site is, however, not used for groundwater abstraction and is not a source of groundwater on the site or in the immediate surroundings. The groundwater flowing under the site is discharged to the ocean and the contamination risk is solely to the site itself and the ocean.

The Malmesbury aquifer is not considered vulnerable or at risk. This is due to the deep water table, low permeability, poor quality, upwelling of groundwater underlying the site into the nuclear raft and discharge to the ocean. No use of the Malmesbury aquifer is known within, surrounding or within 10 km of the site.

3.4.3.2 Aquifer Recharge

Due to the unconfined nature of the upper sediments surrounding KNPS, recharge takes place over the entire area, except where tarmac and cement cover occur. A site recharge value of 15 % of MAP is considered to be representative for the Sandveld aquifer. The groundwater regime is less dynamic in the secondary aquifer and negligible or no recharge to the Malmesbury Group aquifer occurs in the vicinity of KNPS. The Malmesbury Group aquifer is recharged further inland, several kilometres east of the site in areas where the aquifer outcrops.

3.4.3.3 Depth to Groundwater

The water table surrounding KNPS ranges between 2 and 5 mbgl within the primary aquifer (DSSR and PBMR DPP). The depth to groundwater mimics the surface topography. Seasonal and tidal impacts are the dominant factors influencing local groundwater level fluctuations. Boreholes in the Sandveld aquifer monitored since February 2008 to September 2013, using data loggers at the Duynefontein and PBMR potential power plant sites, indicate only minor variations in groundwater levels over the six-years of data collection. Depth to the water table varies according to surface topography, i.e. the higher the topography, the deeper the water table. Water table depths vary seasonally with higher levels during and after the wet season and deeper levels during the dry season. However, seasonal rainfall variations do not significantly affect the groundwater flow direction or groundwater levels across the area surrounding KNPS.

It is predicted that global warming will cause a future increase in sea levels worldwide. Modelling of potential sea level rise at the site has a possible rise in sea level of about 1,2 m over the next 50 years. Numerical modelling carried out for the DSSR of the effects of this rise on the groundwater table indicates that groundwater levels could rise between 0,8 and 0,9 m close to the coast with effects of 0,1 m being propagated approximately 1 000 m inland.

3.4.3.4 Groundwater Flow

Using the available water level elevation data from the numerous boreholes around the KNPS site, groundwater level contour maps were compiled for the primary and secondary aquifers. These contours are shown in Appendix B Figure 6 along with groundwater contours calculated for the backfill material within the cut-off wall. These contours indicate the direction of groundwater flow to be from inland, across KNPS, in a south-westerly direction towards the coast, where it discharges into the ocean. The hydraulic gradient across the site determined from the water table elevation contours is ~ 0,025 decreasing to ~ 0,0125 closer to the coast. Regional groundwater contour data was compiled for the Sandveld and Malmesbury aquifers during the DSSR work.

3.5 Modelling

The intent of this section is also to support assessments, analyses and data interpretation. The information in this section is obtained from [7].

3.5.1 Conceptual Site Model

A conceptual hydrogeological model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. It consolidates the current understanding of the key features of the groundwater system. A regional groundwater conceptual model was developed for the DSSR. The site cross-sections and schematic 3D block model representation that were developed are shown in Appendix C Figures 7 – 12. The main concepts for the conceptual site model are:

- There are currently no downstream users of groundwater but this may change after decommissioning.
- Groundwater at the site is near/at the end of its flow path.
- The receiving environment/downstream receptor of any contamination will be the shore zone/sea but this may change after decommissioning.
- There is a two aquifer system present on site, with an upper intergranular primary aquifer and a lower semi-confined secondary fractured rock aquifer.
- Local direct recharge only affects the primary aquifer. The secondary aquifer is recharged further inland. There is upward leakage of groundwater from the secondary aquifer into the backfill and foundation material within the excavation area. No downward movement from the primary to secondary aquifer is likely due to the hydraulic head. The upper confining 4 – 5 m of weathered clay material was removed from the top of the Malmesbury aquifer during excavation and construction of KNPS, within the excavation area, to expose highly fractured bedrock which leaks groundwater into the overlying backfill material.
- Groundwater flow is from inland, across the KNPS site, in a westerly direction in the primary aquifer and in a south-westerly direction in the secondary aquifer towards the coast, where it discharges into the ocean.
- Depth to the groundwater level at KNPS ranges between 0,76 – 6,15 mbgl (7,24 – 1,85 mamsl respectively) within the cut-off wall and between 2,14 – 5,1 mbgl (5,86 – 2,9 mamsl respectively) outside the cut-off wall.
- Hydraulic conductivity values of the primary aquifer at and around the KNPS site ranges between 0,9 – 5,6 m/d.
- The hydraulic gradient across the site is ~ 0,025 decreasing to ~ 0,0125 closer to the coast. Groundwater therefore flows at a calculated flow rate of ~ 2,6 m/d, which indicates a relatively quick migration across the KNPS site, towards the coastline.
- It is assumed that the bentonite cement cut-off wall is impermeable. The cut-off wall was constructed from 19 – 20 mbgl on the exposed Malmesbury bedrock to 3 mbgl (5 mamsl) at the surface. It is covered by back fill material for 3 m to the levelled surface surrounding the nuclear raft at 0 mbgl (8 mamsl). The surface is covered by tarmac and concrete which surrounds the nuclear raft area. Unpaved areas surround boreholes TW2, TW4 and TW5 within the cut-off wall.
- Leakage of primary aquifer groundwater is occurring over the top of the cut-off wall to the east and possibly along the sides. This can be observed in high water levels in TW1 and Sandveld-type salinities in the monitoring boreholes TW2, TW4 and TW5 which occur within the cut-off wall (excavation) area.
- The nature of the backfill material is not well-known but it is presumed that it consists of a compacted Sandveld sand, silt, clay and carbonate and; that it excludes weathered Malmesbury group clay, silt and rubble. The backfill material will have a lower transmissivity and conductivity than the Sandveld aquifer due to compaction.

- Recharge appears to be occurring in unpaved or grassed areas as demonstrated by very low salinity values and differences in groundwater chemistry at TW2, TW4 and TW5. Leakage of storm water into wells appears to occur in some of the boreholes on occasion, possibly due to ill-fitting manhole covers in TW2, TW3, TW4 and TW5.
- The secondary aquifer groundwater shows upwelling below the nuclear raft area into the backfill material due to exposure of the bedrock during excavation. This groundwater shows a mixing interface with fresh and primary aquifer groundwater at various depths within the monitoring boreholes.
- Natural groundwater quality is marginally saline and of a mixed NaCl and $CaHCO_3$ type in both the secondary and primary aquifers with the secondary aquifer having higher salinity and higher sulphate concentrations.
- There is an inferred interface between ‘fresh’ groundwater from inland and saline groundwater in the shore-zone. This interface may be shifted by groundwater control measures and sea level rise. However, down-hole salinity probing did not detect this zone and so it is unlikely to be a significant boundary at KNPS.

3.5.2 Numerical Modelling

The flow regime in and around the KNPS site is shown in Appendix D Figure 13 as a Schlieren visualisation (using the Line Integral Convolution method), which simultaneously shows the relative flow velocities. It is evident from the figure that the cut-off wall has a pronounced effect on the local shallow primary aquifer groundwater flow regime.

The wall creates an encapsulated “island” within the regional primary aquifer. This diverts regional groundwater flow. It allows only limited flow over the top of the wall and flow through the bottom of the insulated area (via the secondary aquifer), thereby creating a mostly stagnant water body within the encapsulated backfilled area. Flow within the backfilled area is further limited by the concrete raft foundations and associated buildings. Flow velocities within the encapsulated area are below 1 m/a and as low as two orders of magnitude less than velocities in the surrounding primary aquifer which ranges between 50 – 250 m/a.

Limited vertical recharge occurs via unpaved areas and a small piece of grassy soil within the encapsulated area. The inflows described above are balanced by outflows, predominantly over the western and to a minor extent the northern and southern wall sections. These outflows follow then the regional flow gradient in a westerly direction towards the coastline.

Flow directions and velocities derived from the numerical model are therefore in accordance with the conceptual site model in §3.5.1. Groundwater flow is from inland across the KNPS site with significant local deviations of flow paths and velocities, due to the cut-off wall and foundations, in a westerly direction towards the coast. The simulation indicates only limited flow within the encapsulated area.

Dissolved substances (solutes) are transported in groundwater by a combination of advective and dispersive flow mechanisms. While advective transport describes the bulk movement of solutes along the mean direction of fluid flow, dispersive transport accounts for the mixing and spreading of solutes along and transverse to the direction of flow due to local variations in interstitial fluid velocities. These variations are a result of the velocity profile in individual pores due to friction, differences in pore sizes, differences in path lengths, the effect of converging and diverging flow paths as well as aquifer material heterogeneities. A uniform longitudinal dispersion length of 20 m was assigned for the aquifers and backfill material.

3.5.2.1 Effectiveness of Existing Boreholes based on Numerical Modelling

The simulated one-year capture zones of the monitoring boreholes shown in Appendix D Figure 14 reflect, as expected, the distribution of the flow velocity field shown in Appendix D Figure 13, with consideration of partially higher transport velocities due to longitudinal dispersion. Accordingly, the capture zones of monitoring boreholes P2a and P2b outside of the cut-off wall have higher flow velocities and cover a much larger area (longer and wider area specifically around 80 m upstream with a width of 40 m) than the remainder of the monitoring boreholes within the cut-off wall or borehole TW3 at the sea water intake.

While the capture zones of monitoring boreholes TW1 and TW2 extend some distance (50 m and 20 m respectively) upstream and beyond the cut-off wall for TW1 (indicating shallow groundwater flow over the wall), the capture zones of boreholes PN1, PN2, PS1, TW4 and TW5 are essentially limited to their immediate vicinity due to low flow velocities within the cut-off wall backfill material. It is evident from the distribution of the capture zones that none of the existing boreholes are efficient in monitoring potential downstream migration of pollutants across/over the cut-off wall towards the ocean.

3.6 Monitoring

The information in this section is obtained from [7, 12].

3.6.1 General

The use of boreholes for monitoring can be adjusted as assessed by the Programme Owner.

3.6.2 Contamination Sources

There are two main types of contamination sources at KNPS:

- Point sources: well-defined locations, such as storage tanks, workshops or process units, where substances which could contaminate groundwater through localized spills or leaks are stored, handled or used.
- Diffuse sources: less-well-defined areas where groundwater contaminants could originate. For KNPS the major diffuse source on site is the storm water system (SEO), which is considered as “degraded” and may have a multitude of leak points in any given area.

All other underground pipelines not housed in buildings, have a second barrier, except the SEO system. However, the second barrier may leak. Other structures, such as underground sumps and galleries, are not inspected due to accessibility. Some of the point sources also discharge effluent to the SEO system, which is considered a diffuse source.

The SEO system in some parts is in direct contact with the soil. Storm water and the effluent streams going into SEO are intended for discharge into the sea, but may leak from the SEO’s underground pipework on-route to the discharge points. SEO is divided into two major catchments, north and south, which discharges into the intake basin and outfall, respectively. The SEO catchments, intakes from discharge areas and current sampling locations are shown in Appendix E Figures 15 – 17 [7, 13] respectively. The sources of effluent running into the SEO and their main chemical components at each area are listed in Appendix E Tables 2 – 3.

3.6.3 Existing Boreholes and their Effectiveness Summary

The boreholes consist of three types. Small piezometers installed as seismic holes three of which are used for monitoring (PS1, PN1 and PN2), standard monitoring boreholes with steel and PVC stick-up and marker poles (P2a and P2b) and large diameter wells (TW1 – 5) installed during excavation of the nuclear island. The aforementioned boreholes and their water contents, besides TW3, were inspected using a down hole camera and using a bailer respectively [12].

Information gathered from monitoring of wells TW1 – 2 and TW4 – 5 is limited to monitoring of upwelling of the secondary aquifer and soil-cement foundation conditions. Well TW3 monitors the mixed secondary aquifer and sea water interface. The lack of slots in the casings indicate no through flow of water from the nuclear island groundwater. Wells TW1 – 2 have better capture zones compared to wells TW3 – 5 which are limited to immediate vicinity. Wells TW1 – 5 are useful for monitoring the secondary aquifer.

The seismic piezometers PS1, PN1 and PN2 are drilled into the concrete base of the nuclear island. Due to their expected slot configuration based on piezometer depths and PN2 slot configuration, it is determined that they are not actually monitoring the groundwater of the sand backfill of the nuclear island. Their capture zones are also limited to immediate vicinity. As these piezometers are drilled into concrete they most likely contain old stagnant water at the time of the aforementioned camera and bailer inspections [12].

Boreholes P2a and P2b have slots along most of their lengths and their capture zones cover a large area. They are useful for monitoring of the primary aquifer outside the nuclear island area.

As contaminants enter the soil and groundwater from the surface, higher contamination levels are expected closer to the surface. The existing boreholes are therefore inefficient for monitoring contamination due to their locations and configurations. The locations and historical data for existing boreholes are shown in Appendix F Figure 18 and Tables 4 – 7. Tables 6 – 7 also show boreholes other than the above mentioned. The boreholes GCS01 – GCS10 in Table 7 are the Aquarius wellfield boreholes.

3.6.4 New boreholes

The proposed locations and summary of the new boreholes for monitoring the primary aquifer, in Phase 2, are shown in Appendix G Figure 19 and Tables 8 – 10. The proposed locations and summary of the new boreholes for monitoring the secondary aquifer, in Phase 3, are shown in Appendix G Table 11. Target contamination sources and the specific rational for each borehole location are listed in Tables 8 – 11. Should these exact locations prove to be underlain by infrastructure, the position can by moved by 0,5 – 1 m maximum radius around the proposed location. Guidance for the design specification for the new boreholes, borehole cover boxes, borehole concrete base and drilling method is provided in [12].

3.7 Borehole Maintenance

The boreholes should be maintained as deemed necessary. The condition of the boreholes should be monitored. External visual inspections should be performed quarterly. Downhole camera inspections should be performed 3 yearly. These frequencies may be adjusted.

3.8 Sampling

3.8.1 General

Approved sampling procedures shall be used. The sampling depths in wells TW1 – 5 may be limited by the presence of large concrete blocks in the wells which are used for Civil Engineering testing [12]. Access to well TW3 is via a trap door and a cat ladder and is not directly accessible from the surface.

3.8.2 Method for Sampling Soil during Drilling of New Monitoring Boreholes

Two representative samples of soil should be collected during drilling of each borehole.

- One sample to represent the depth interval from surface to 0,5 mbgl.
- One sample to represent a 1 m depth interval from just above to just below the standing water table. This will be from the depth that drill spoil becomes wet to the point where it is very moist, with free water running from samples removed from the auger.

The intention of taking a sample from the near surface sample is to test for contamination of soil due to infiltration of contaminated water or substances from the surface, through damaged paving for example. The intention of the soil sample from the soil interval crossing the water table is to test for the accumulation of contaminants in the soil near the water table due to the passage of contaminated groundwater through soil at this depth.

Samples should be collected by mixing the soil representing the relevant depth interval on a clean plastic sheet laid on the ground and transferring it to a laboratory-supplied plastic bag, sufficient to contain 2 – 3 kg of soil. The laboratory may specify smaller sub-samples in glass jars for certain analyses which should be taken from the well mixed composite sample. Samples for organic contaminants should be kept cold in a cooler box with ice packs, at 4 ^{0}C or less, until analysis [12].

3.8.3 Method for Sampling Groundwater

In the case of free-phase hydrocarbon products (i.e. a floating layer of petrol, diesel or oil on groundwater), the thickness of the floating layer should be determined by using an interface meter. Care should be taken in using a bailer to determine the floating layer thickness as the main limitations are the difficulty in precise placement of the bailer to intersect the product/water interface, and the decrease in accuracy due to the tendency of viscous product to bypass the bailer entry point, thus resulting in less products in the bailer than actually exists in the monitoring well. If it is necessary to identify the product, a sample of the floating layer can be collected using a bailer [12].

Where there is no evidence of free-phase hydrocarbon products, samples should be collected using the low-flow sampling method of [14] as advised by [12]. Samples should be kept cold in a cooler box with ice packs, at 4 ^{0}C or less, until analysis [12].

3.8.4 Sampling Frequency

In instances where licenses or permits have been issued by authorities, license or permit conditions will specify the frequency of analyses and constituents to be tested. In instances where licenses or permits have not been issued, frequencies should be based on the initial risk assessment.

At any groundwater sampling facility, initial sampling should be done at a frequency high enough to obtain statistically valid background information irrespective of the frequencies required by licenses or permits. For any long-term monitoring facility, three initial sampling exercises, all within 90 days and not less than 14 days apart, are suggested. Depending on the variation amongst these values, future sampling may be planned. A three-monthly sampling frequency will be sufficient in most instances.

Good practice at active or newly built power stations should be every three months for ground and surface water. At KNPS the frequency may be adjusted to 6 monthly or yearly as decided by the Programme Owner due to the time taken for groundwater to collect in boreholes. The duration of sampling will be driven by the risk posed. Should the risk be insignificant, sampling could be discontinued after consultation with the DWS.

3.8.5 SEO Sampling

It was intended that the SEO system be monitored for tritium via sampling at locations labelled 1 - 11 in Appendix E Figure 15 but due to low or no water flow, sampling was not practical. As previously mentioned, the SEO system is currently sampled at 3 locations as can be seen in Appendix E Figure 17. Even with this strategy, samples are not always obtained as the low level waste channel is often dry. During dry periods the outlet is often covered with sand.

The Chemistry Group identified during a job observation that the SEO south outlet discharges into a square basin of 2 m length which is filled with sea water. The basin is several meters deep. Due to the level of the SEO outlet relative to the sea water level, it isn’t always possible to get a representative SEO sample. Often some sea water enters the sampling container which is difficult to prevent given the SEO outlet and basin configuration. The consequence is that the historical trend up to now for the SEO south outlet may not be representative as it may have contained sea water which could have diluted or contaminated the sample. The ESL Programme is pursuing acquiring more suitable sampling devices.

3.9 Soil and Groundwater Analysis

The KNPS radiochemistry laboratory is proficient in the analysis of radionuclides and will perform this on site. Non-radioactive samples (and radioactive samples if need be) should be analysed by a SANAS accredited laboratory that shall be suitably equipped to execute the analysis.

3.9.1 Analysis Categories

The required analyses falls into 2 categories viz. Comprehensive and Indicator analyses [4].

3.9.1.1 Comprehensive Analysis and Frequency

For all new sites and first-time monitoring at existing sites, a comprehensive analysis is required. It is essential that accurate background levels, for as wide a range of constituents as possible, be established at the outset. This will usually include a complete macro analysis as well as an analysis for trace elements, such as chromium radionuclides at KNPS. The comprehensive analysis should be repeated during the operational period at least every three to five years or as guided by the risk posed, at decommissioning of the operation [1, 3] and as additionally required by the decommissioning plan (when developed).

3.9.1.2 Indicator Analysis

Indicator analysis may be performed once comprehensive analyses have been completed. This process may continue until undesirable trends are observed. This will keep analytical costs to a minimum, but still provide enough information, upon which further action can be initiated, if necessary. Depending on the type of waste handled, so-called "contamination indicators" for KNPS may be identified. Examples are the following:

- The so-called sewage variables, such as pH, TDS, COD, NH_3, NO_3, NO_2, PO_4 and E. coli.
- General waste disposal variables, such as COD, Cl, NO_3 and NH_3.
- Nuclear power station contamination variables such as specified isotopes e.g. tritium, pH, EC and TDS.
- Hydrocarbon contamination variables, such as GROs, DROs, PACs and PCBs for transformer areas.

3.9.2 Groundwater Contaminants of Concern

Two contaminants should be noted for their potential long-term environmental impact [7]:

- Tritium: radioactive heaviest hydrogen isotope, which is enriched in primary coolant water in nuclear plants.
- PCB: dielectric fluids, widely used in electrical equipment as constituents of transformer coolant oils and in capacitors and; known for their environmental persistence and toxicity.

3.9.2.1 Tritium

According to a study conducted at KNPS [7] groundwater analysis for the PBMR project found enriched tritium concentrations in groundwater samples from the plant site, at up to 5,1 Bq/l (42 TU). Local rainwater has a natural tritium content of about 0,36 Bq/l (3 TU).

Further monitoring has established that elevated levels of tritium are a consistent feature of groundwater quality near the plant buildings. These concentrations are anomalous and represent a minor unmonitored release of radioactive material to the environment.

The KNPS study identified the following as being the most likely sources of tritium in groundwater:

- Leakage from the storm water system (SEO), which in turn receives effluent from:
  - The sewage treatment plant (SEU): The effluent has an average tritium level of 1500 Bq/l.
  - Condensate from the ASG (auxiliary feed water system) flash tanks: The tritium levels in the flash tanks are as high as 10 000 Bq/l.
- Steam releases from the secondary circuit (e.g. a steam dump from the GCT – turbine bypass system).
- Releases of steam or condensate via the DVN stack (nuclear auxiliary building ventilation system).

There is also the possibility of leaks from underground infrastructure; one location which could be a source of tritium in the groundwater is the ATE regeneration facility at the demineralized water plant. The KER system (including piping) is inspected monthly but the time taken to identify and repair leaks could also be a source of tritium in the groundwater.

3.9.2.2 PCB

According to Eskom [7], no new PCB-containing products have been purchased since 1979. All transformer oils in use at KNPS have been tested for PCB content. PCB has only been detected in transformer oils at two locations, at very low levels:

- The Turbine hall, below the 24 kV breaker (1 GEX 001 TR) – 6 ppm PCB
- The Sea water chlorination plant (CTE 001 TX) – 3 ppm.

In addition, it was determined [7] that all PCB-containing capacitors have been replaced, except for two in the CAS electrical rooms, which may contain PCB (6 SSC 001 DL and 6 SSD 001 DL). They are scheduled for replacement. Therefore PCB's on site are of historical significance only in areas where they were used.

3.9.3 Constituents to be Analysed in Soil and Groundwater

Appendix H Tables 12 – 14 list the baseline analyses to be conducted on soil and groundwater samples; sampling location (additionally frequency for groundwater) and; rationale for the testing based on the baseline chemistry requirement. This information can be compared to existing data, data from the primary aquifer (published and in reports) and will be a basis against which other monitoring data will be compared [12].

3.9.4 Radionuclides to be Analysed in Soil and Groundwater

Samples will be analysed for tritium. If the tritium levels are below detectible using on-site techniques then a baseline is recommended using off-site laboratories [8]. For routine monitoring and analyses after the baseline is established, analyses using off-site laboratories is not required.

If the investigation level for tritium is triggered, then samples will be analysed for gamma emitting radionuclides which include Mn-54, Fe-59, Co-58, Co-60, Zn-65, Ag-110m and Cs-137. Other radionuclides which are measurable and identifiable shall also be monitored. In instances where licenses or permits have been issued, license or permit conditions will specify analyses and constituents to be tested.

3.10 Acceptance Criteria

In addition to the acceptance criteria below, acceptance criteria for the site groundwater will also be determined when the KNPS decommissioning phase is developed taking into account safe consumption of the site groundwater should it be consumed by the public after KNPS is decommissioned. Development of acceptance criteria should account for seasonal variations.

3.10.1 Acceptance Criteria for Radionuclides

The radionuclide acceptance limits are as advised by [8] and tabled in Appendix I Table 15. The reporting level for tritium in drinking water in the ESL programme is 2050 Bq/l. An investigation level at approximately 10% (200 Bq/l) is adopted as a conservative approach. As a comparison, the investigation levels established in the EU is set at 100 Bq/l. If the investigation level for tritium is triggered then samples will be analysed for gamma emitting radionuclides which include Mn-54, Fe-59, Co-58, Co-60, Zn-65, Ag-110m and Cs-137. Other radionuclides which are measurable and identifiable shall also be monitored.

The Minimum Detectable Activity (MDA) set at 50 Bq/l needs to be below the investigation level and is aligned with current detection capability on site. Site detection capability is aligned to industry norms. As a comparison the US EPA requires a detection level of 37 Bq/l for drinking water. If the tritium levels are below detectible using on-site techniques then a baseline is recommended using off-site laboratories. For on-going monitoring and analysing after the baseline is established, analysis using off-site laboratories is not required.

The regulatory authorities in South Africa have not established a drinking water standard specifically for tritium. However, there is sufficient international and national guidance to develop site specific criteria and the NNR and DWS have established dose criteria that can be used.

The NNR has established maximum public dose criteria for a licensed nuclear installation (regulated action governed by a nuclear license). The NNR [15], have established dose and activity criteria for exemption or exclusion from regulatory control. Radioactivity that contributes to less than the 0,25 mSv/y becomes automatically eligible for exemption. This corresponds to tritium activity of around 25 000 Bq/l. The Regulations allows exemption above these levels on a case by case basis. So while this might be possible, it is not guaranteed. The maximum limit for exposure for the public from an authorized action is 1 mSv/y. So the maximum allowed limit that might be agreed to by the NNR, once optimization measures are considered, could be anywhere between 0,25 mSv/y and 1 mSv/y.

The DWS have established water contamination guidelines where the dose limit is 1 mSv/y and the trigger for dose reduction (ALARA) is between 0,1 mSv/y and 1 mSv/y. It is conservatively assumed that in order to meet the NNR exemption level of 0,25 mSv/y and the DWS ALARA trigger of 0,1 mSv/y, a maximum acceptable guideline level of 10 000 Bq/l is adopted. This is also aligned with the WHO drinking water standard limit of 10 000 Bq/l.

3.10.2 Acceptance Criteria for Non-radioactive Contaminants

The DWS has not yet determined the resource quality objectives for the Berg-Olifants WMA within which KNPS falls. For sites without licenses pertaining to groundwater such as KNPS which does not have any water permit or license conditions related to groundwater, the drinking water standard [9], the statutory general authorisation [10] and the US EPA drinking water regulations [11] are used as acceptance criteria which is deemed conservative. The investigation level is set at the acceptance criteria limits.

Should the baseline results be higher than these acceptance limits by an amount Δ and the cause is determined to be from KNPS, then new acceptance criteria can be developed based on the background results (excluding the KNPS contaminant contribution results) times (100 + Δ)%. Should these new acceptance criteria be developed, Δ can be at least 10%.

The non–radionuclide contaminant acceptance limits are tabled in Appendix I Table 16 as advised by [9]. The associated risks for domestic water as determined by [9] are as follows:

- Health risks: parameters falling outside these limits may cause acute or chronic health problems in individuals.
- Aesthetic risks: parameters falling outside these limits indicate that water is visually, aromatically or palatably unacceptable.
- Operational risks: parameters falling outside these limits may indicate that operational procedures to ensure water quality standards are met, may have failed.

3.10.2.1 Acceptance Criteria for Additional Non-radioactive Contaminants

The drinking water standard [9] does not provide acceptance limits for phosphates. The acceptance limits for phosphates is tabled in Appendix I Table 17 as advised by [10]. The drinking water standard [9] and the statutory general authorisation [10] do not provide acceptance limits for PCB and PAH. The acceptance limits for PCB and PAH are tabled in Appendix I Table 18 based on the US EPA drinking water regulations [11].

The US EPA set a Maximum Contaminant Level Goal (MCLG) for each contaminant in public water systems. The MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety. MCLGs are not enforceable in the US.

The MCLG is not a legal limit set for public water systems. It is based solely on human health. For known cancer-causing contaminants the MCLG is set at zero. This is because any chemical exposure could present a cancer risk.

The Chemical Contaminants Rules also set a Maximum Contaminant Level (MCL) for each contaminant. The US EPA sets MCLs as close to the health goal as possible. The MCL weighs the technical and financial barriers with public health protection.

3.11 Corrective Action

3.11.1 General

If the investigation level is triggered, the cause and impact should be assessed. The event should be classified in accordance with [16]. Reporting to the NNR and DWS can be performed. Pollution source management should be implemented. It should be determined whether remediation is required and the type of remediation.

3.11.2 Pollution Source Management

Effective pollution prevention reduces the management and financial burden associated with remediation during the operational and especially closure phases. Therefore all reasonable efforts should be made to prevent pollution and to minimise impacts. Additionally, principal measures should be taken from an environmental duty of care provision (Section 19 of [1] and Section 28 of [2]) and pollution minimisation to prevent, to the extent reasonable, spills and leaks from occurring and contaminating the ground water. Pollution source management detail is as guided by [4] some of which includes:

- Monitoring, reducing and preventing spills and leakages.
- Repairing plant components and leaking storm water drains.
- Defining temporal impacts profile.
- Prior to decommissioning, removing potential sources of pollution such as hydrocarbon and radionuclide contaminated soils and disposing of such pollution sources at an authorised disposal facility.

3.11.2.1 Defining Temporal Impacts Profile

It is necessary to evaluate the potential pollution impacts that will persist for at least 100 years (or such other time as is agreed with the relevant authorities) after closure of KNPS. These time-based or temporal impact profiles should be prepared for all alternatives being considered. This is to ensure that a pollution-prevention option with the best short-term benefit but poor long-term benefits is not inadvertently selected.

3.11.3 Groundwater Remediation

Groundwater remediation means the interim or permanent elimination through mitigation or reduction of contaminants that pose human health consequences or threats to the environment. Sites that are identified through the risk assessment process as having a high risk to human health or the environment will be considered as a priority site and may require immediate remediation by Eskom. Financial and technical constraints present hardship in the restoration of all water resources to pristine condition. For this reason, remediation strategies make use of a risk-analysis approach to rank remediation priorities. The remediation process and options is as guided by [4].

3.12 Radiological Protection for Borehole Drilling and Sampling

The radiological consequence for workers responsible for the construction of the boreholes has been assessed. As mentioned in §3.9.2.1, based on the historical analysis results, the levels of radioactivity in the soil is expected to be low.

Tritium in the soil comes from leakage of the SEO system (highest concentration), from the secondary plant discharges via the atmosphere and possibly from leakage of the ATE and KER systems. The route via the SEO system would result in dilution of the Tritiated water, with no risk of accumulation and concentration to levels higher than the initial level in leaking water. The tritium levels would therefore be below that of the plant secondary system, and the latter does not warrant RP measures. Following the SGR Project, it is anticipated that tritium concentrations in the secondary plant will be significantly lower.

Gamma emitters are generally not detected in the plant secondary system. In the event of leakage thereof directly to groundwater, accumulation due to deposition or other concentrating mechanisms is unlikely to cause radionuclide concentrations of concerning levels. In addition to the low risk of accumulation, water samples have not contained measurable gamma emitters for many years.

Samples from boreholes suspected to have a potential for radionuclide contamination of concerning levels should be taken during initial borehole drilling and submitted to a Radiochemistry Lab for analysis by Gamma Spectrometry. In the unlikely event that radionuclide accumulation does occur in the soil, it will be detected in the analysis and RP measures instituted if warranted.

3.13 Safety Screening

Safety Screening S10702 was performed and concluded that this programme does not impact the KNPS Design and Licensing Bases.

3.14 Summary of Programme Tasks

A summary of the tasks in this programme is presented in Appendix J Table 19.

3.15 Programme Improvements

- Obtain the numerical model which is retained by the contractor [7].
- The EPRI groundwater protection guidelines [21] are referenced in the Eskom groundwater governance guidelines [4]. However, perform a gap analysis between this Manual and the EPRI guidelines especially to improve groundwater protection against contamination from radioactive substances.

4. Acceptance

This document has been seen and accepted by:

Name	Designation
M Dollie	Senior Advisor - Materials Reliability
S Cyster	Senior Advisor - Materials Reliability
D Jeannes	Manager - Nuclear Environmental
H Morland	Senior Chemist – Chemistry
T Karsten	Middle Manager – Radiation Protection
P Ellis	Senior Radiation Protection Assistant – Radiation Protection Alara

5. Revisions

Date	Rev.	Compiler	Remarks
August 2019	0	Z Mia	Draft document. International operational experience at nuclear power stations has shown that groundwater contamination occurs from a variety of sources and is due to various causes. For example, the US nuclear industry has subsequently undertaken a Groundwater Protection Initiative at the direction of the NSIAC. In response to industry best practice, KNPS developed this site-specific Groundwater Protection Programme.
June 2020	1	Z Mia	Authorised document.

6. Development Team

The following people were involved in the development of this programme:

- Zia Mia
- Mubeen Dollie
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- Herman Morland

7. Acknowledgements

Special thanks are extended to the development team in §6 for their voluminous contribution and the reviewers in §4 all of whom contributed significantly.

Appendix A – Process

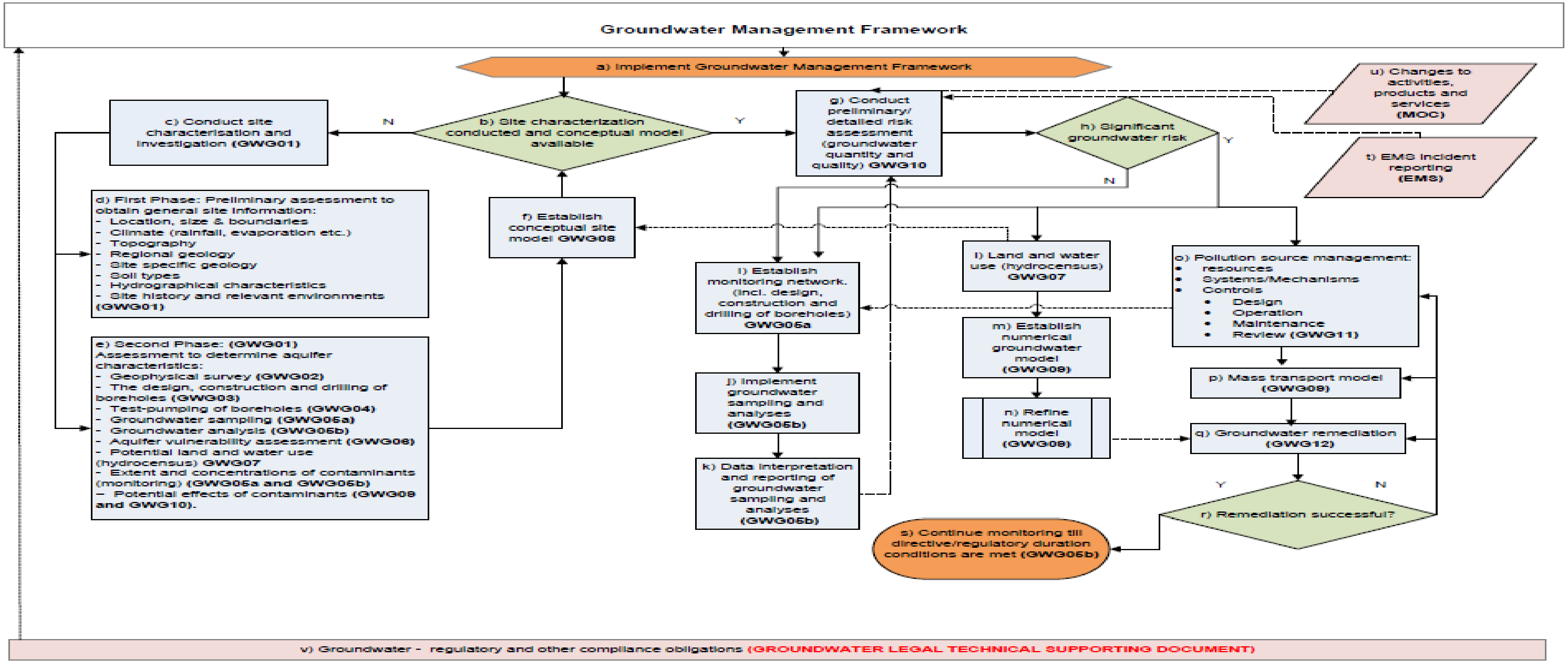

Figure 1: Process

Table 1: Simplified descriptive narrative of the process in Figure 1

Reference in Figure 1	Task / Decision / Input	Guideline Reference	Description
a) Implement a groundwater management framework	Task		The process in Figure 1 defines the essential management activities and technical elements that are required to implement sound groundwater management practices.
b) Site characterisation conducted and conceptual model available	Decision	• Groundwater Site Characterisation Guideline (GWG01) • Conceptual Site Model Guideline (GWG08)	Determine whether a site characterization and subsequent conceptual model has been completed. • If yes (and the quality of the site characterisation and conceptual model is adequate), continue to g. • If no, continue to c.
c) Conduct site characterisation and investigation	Task	• Groundwater Site Characterisation Guideline (GWG01)	All hydrogeological studies require an initial conceptual model that captures the understanding of the hydrological system. Existing knowledge is used to develop a conceptual understanding of the groundwater system. The design of subsequent information gathering is based on the initial conceptual model and information gathered during further investigation is used to refine the conceptual model. Both phases d) and e) should be completed where the need for groundwater monitoring has been established by regulatory obligations, e.g. WUL, etc.
d) First phase: Preliminary	Task	• Groundwater Site Characterisation Guideline (GWG01)	The preliminary assessment is required to obtain general site information:

assessment		• Conceptual Site Model Guideline (GWG08)	• Site location, size and boundaries; • Climate (rainfall, evaporation, etc.); • Topography; • Regional geology; • Site-specific geology; • Soil types; • Hydrographical characteristics; • Current, previous and potential land and water use for the site and nearby areas; and • Site history (previous owners, activities, associated contaminants, etc.). All relevant, existing information is identified and key texts should be reviewed. Central to the hydrogeological study is the identification of boreholes in the area and all users and uses that could be impacted. The National Groundwater Archive, GRIP and WARMS of DWS are a good starting point to identify boreholes, but databases may not be up to date or may contain incorrect information.
e) Second phase: Assessment to define the spatial extent and risk of groundwater impact to human health, etc.	Task	• Groundwater Site Characterisation Guideline (GWG01) • Geophysical Survey Guideline (GWG02) • Borehole Drilling Construction & Design Guideline (GWG03) • Aquifer Testing Guideline (GWG04) • Groundwater Monitoring Guideline (GWG05a) • Groundwater Sampling Guideline (GWG05b) • Aquifer Vulnerability Assessment (GWG06) • Hydrocensus Guideline (GWG07)	Field studies are used to characterise the sub-surface environment. The conceptual model of the study area will help to identify issues that require improved understanding, while the conceptual understanding of the mechanism by which impact occurs will help to prioritise issues to be clarified. Activities include: • Geophysical survey; • Design, construction and drilling of boreholes; • Aquifer testing; • Groundwater sampling and analysis; • Aquifer vulnerability assessment; • Hydrocensus; • Extent and concentrations of contaminants (monitoring); and

			• Potential effect of contaminants.
f) Establish conceptual site model	Task	• Conceptual Site Model Guideline (GWG08)	A conceptual (hydrogeological) site model (CSM) is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, details the gaps in the existing knowledge base and assists in the understanding of possible future changes. The development of an appropriate CSM is required to ensure that the groundwater evaluation/assessment achieves its objectives. The CSM development process may need to include people with a range of skills (hydrology, hydrogeology, climate, soil etc.) and represents a key point in the site assessment process. The level of complexity of the CSM should be appropriate to both the objectives of the site, its characteristics and available data. In the early phase of groundwater assessment, when basic data on these items are usually scarce, it may only be possible to produce a rough concept of the real system. Later on, the level of complexity that can be depicted will increase as more data becomes available. Besides playing an important role in preliminary analysis of the groundwater system, the CSM is the basis for design of a groundwater monitoring programme. Data collected for the CSM, either existing or new, should be analysed for indications of potential impacts on receptors. The development of a CSM should be one of the first actions of the site characterisation, even if this first attempt is very simplified.
g) Conduct preliminary/detailed risk assessment (groundwater quantity	Task	• Risk Assessment Guideline (GWG10)	Risk assessment is the process or method of determining if an activity (human or natural) will have a negative impact on human health, agricultural activities or the environment. Therefore, risk assessment is a decision-making tool for prioritising actions, reducing expenditure and setting management targets for

and quality).			environmental protection. In its simplest form, risk assessment involves (sometimes qualitative or subjective) decisions on: • The probability of an adverse effect occurring as a result of an activity; and • The severity of the consequences if an adverse effect does occur. This combines both the likelihood that an event will take place (e.g. a spill of some toxic chemical in a recharge area and the chemical dissolving in the groundwater) and the likelihood that it will cause harm if it does take place (e.g. people who drink the water become ill). Groundwater risk-based approaches must take into account: • The source(s) of risk; • The groundwater pathway connecting the source to the receptor; and • The nature of the receptor(s). An initial screening-level assessment should be undertaken to determine the critical receptor(s) for a particular source term on which impact will be the most severe. A fully integrated quantitative risk assessment should use the 'source-pathway-receptor' model and involves the following components: • Assessing of the source terms and properties of the chemical substance (solubility, infiltration potential, toxicity, etc.); • Identifying and confirming the beneficial uses in the vicinity of the site through a hydrocensus and review of expected land use; • Determining groundwater flow direction and the potential exposure of the receptors to the chemical substances (e.g. the site may be located hydraulically down-gradient of a

			sensitive receiver and an assessment has demonstrated that impacted groundwater will migrate towards the receiver); and • Assessing the impact on water quality in the receiving environment compared to DWS water quality criteria. Eskom requires that a quantitative risk assessment be performed in the following circumstances: • Where ecosystem protection is the principal beneficial use and harm to water resource/ecosystem may occur; and • The beneficial uses of the groundwater are for a potable water supply and harm to (the) water users may occur.
h) Significant groundwater risk	Decision	• Risk Assessment Guideline (GWG10)	If significant groundwater risk exists (yes) continue to i), l) and o). All three activities should be performed. If no significant groundwater risk exists, only perform i). It is, however, important to note that should activity k) (data interpretation and reporting) indicate high levels of contamination or risk, which was not detected/anticipated during phase g) (preliminary/detailed risk assessment), phase g) may have to be repeated and the need for groundwater remediation, activity q), may still have to be initiated immediately in high-risk scenarios.
i) Establish monitoring network (including design, construction and drilling of boreholes)	Task	• Groundwater Monitoring Guideline (GWG05a) • Groundwater Sampling Guideline (GWG05b) • Borehole Drilling Construction & Design Guideline (GWG03)	It is important to prepare a good site-specific monitoring plan. The CSM and risk assessment should be used to structure the network design based on a geophysical survey. A groundwater monitoring network should contain monitoring positions that can assess the groundwater status in certain areas. Boreholes should be grouped/classified according to the source-pathway-receptor indication. Groundwater monitoring is the meaningful measurement of variables and can be done through the following: • As a minimum, a once-off test during initial impact assessments;

			• Routine tests as part of compliance with license conditions, or • Ongoing groundwater investigations to quantify impact on the groundwater resource or sensitive receptors. A groundwater monitoring network should contain monitoring positions that can assess the groundwater status in certain areas. A monitoring point should be representative of the response of a part of the regional groundwater system or the system as a whole. Examples of such stresses are the drawdown of the water table caused by pumping or contamination of the groundwater system by contamination sources, such as ash dumps or coal stockyards. Monitoring networks can be designed to operate on local, regional and national scales. A source-specific monitoring network is intended for a single waste management facility, whereas regional monitoring relates to a combination of waste management facilities, such as those usually present at power stations.
j) Implement groundwater sampling and analyses	Task	• Groundwater Sampling Guideline (GWG05b)	It is important to prepare a good site-specific sampling plan. The plan will describe where, what, why, how and when Eskom requires sampling and who will be doing it. This should be based on WUL license conditions and contaminants of concern. Water samples must be analysed by a recognised analytical laboratory that uses approved analytical procedures. Groundwater quality is characterised by a large number of parameters, including physical, chemical and biological types. The interest in these parameters differs with the objectives of the analysis. Therefore, the sampling and monitoring procedures will also differ. These objectives may be of a general type, for instance, "general groundwater characterisation" related to the actual situation and the potential for use or they may be more specific, such as conducting studies of groundwater quality under the influence of contamination or remedial measures. The complexity of groundwater quality problems usually

			increases with the intensity of groundwater development and so does the need for more specific data collection procedures.
k) Data interpretation and reporting of groundwater sampling and analyses	Task	• Groundwater Monitoring Guideline (GWG05a) • Groundwater Sampling Guideline (GWG05b)	Data should be interpreted in accordance with the background water quality, WUL and other license/authorisation conditions, receptor-specific quality criteria (e.g. drinking water) and end land use water resource quality objectives, where relevant and appropriate. Conclusions should be drawn based on the relevant legal obligations applicable and the risk to Eskom.
l) Land and water use (hydrocensus)	Task	• Hydrocensus Guideline (GWG07)	A hydrocensus is essentially a site familiarisation involving the collection of important groundwater data from the study area and surrounding environments to an Eskom facility such as a power station. It comprises a census of key boreholes, springs and any other groundwater-related information. The objective is to identify the potential (pollution) risk and depletion risk to receptors – particularly groundwater users such as communities and farmers. The extent (intensity and area covered) of the hydrocensus will depend upon the level of the study (national, local or site-specific) and the particular requirements of the study, but it must provide wide coverage of information far enough outside Eskom's operations to allow an overview of the aquifer system(s) to be captured at the necessary level of detail. The information obtained, such as quality and static water levels assist in defining the groundwater system regionally.
m) Establish and refine a numerical groundwater model	Task	• Numerical/ Analytical/Risk- based Groundwater Modelling Guideline (GWG09)	A groundwater model is a numerical representation of a groundwater flow system that attempts to mimic the natural processes in nature. It is a simplified version of a natural system, compiled with geological, hydrogeological, hydrological and meteorological data, which utilises a governing equation to incorporate all this data to simulate the hydraulic properties of the groundwater system. For some assessments, particularly at the site-specific level, it may be

			desirable or necessary to prepare a numerical, analytical or risk-based model of the groundwater system. Where a model is prepared, predictions of the long-term behaviour of the groundwater system under the planned development can be made and simulations of certain aspects being investigated, such as migration of pollution plumes with time, can be undertaken. Once the model has been finalised, this can be used as input for risk-based decision-making.
n) Refine numerical groundwater model	Task	• Numerical/ Analytical/Risk- based Groundwater Modelling Guideline (GWG09)	Update and refine the model with time series information in order to improve its accuracy.
o) Pollution source management	Task	• Pollution Source Management Guideline (GWG11)	The core of integrated water management at Eskom operations should be, in the first instance, to seek to optimally implement pollution prevention measures. If these measures do not address all the water management issues, then the operation should secondly develop and implement appropriate water reuse and reclamation strategies. These strategies may include a greater or lesser degree of water treatment in order to render the water suitable for reuse. If there is still a residual water management problem, then the operation could evaluate and negotiate options with regulators for the discharge of such water to the water resource.
p) Mass transport model	Task	• Numerical/ Analytical/Risk- based Groundwater Modelling Guideline (GWG09)	Reactive transport modelling in porous media refers to the creation of computer models integrating chemical reaction with transport of fluids through the earth's crust. Such models predict the distribution in space and time of the chemical reactions that occur along a flow path.
q) Groundwater remediation	Task	• Groundwater Remediation Guideline (GWG12)	If pollution source management has failed to prevent or negate the effects of significant risks to human health and the ecosystem through a risk assessment, the remediation process can be embarked upon in consultation with regulators. If remediation is not effective, the pollution source management aspects might still be ineffective and this should be revisited and alternative remediation options considered. If

			remediation is successful, continue with monitoring in accordance with the remediation plan or in accordance with the remediation directive requirements.
r) Remediation successful?	Decision	• Groundwater Remediation Guideline (GWG12)	If the groundwater remediation is successful, continue to activity s). If not, re- assess adequacy of activities o), p) and q).
s) Continue monitoring till directive/regulatory duration conditions are met	Task	• Groundwater Monitoring Guideline (GWG05a) • Groundwater Sampling Guideline (GWG05b) • Groundwater Remediation Guideline (GWG12)	Ensure compliance to regulatory obligations e.g. directives and approved remediation plans with regard to duration and other monitoring specifications.
t) EMS incident reporting	Input	• ISO 14001	Ensure that all environmental incidents (especially spillage and external complaints from water users are brought to the attention of the geohydrologist/consultant. It may trigger an update requirement to activity g).
u) Changes to activities, products and services	Input	• Management of change	Ensure that any changes in activities, products and services are brought to the attention of the geohydrologist/consultant as it might trigger an update of activity g).
v) Regulatory and other requirements/ obligations	Input	• Technical Legal Supporting Document	Ensure that the latest regulatory obligations pertaining to groundwater are considered in the implementation of the GMF.

Appendix B – Site Details

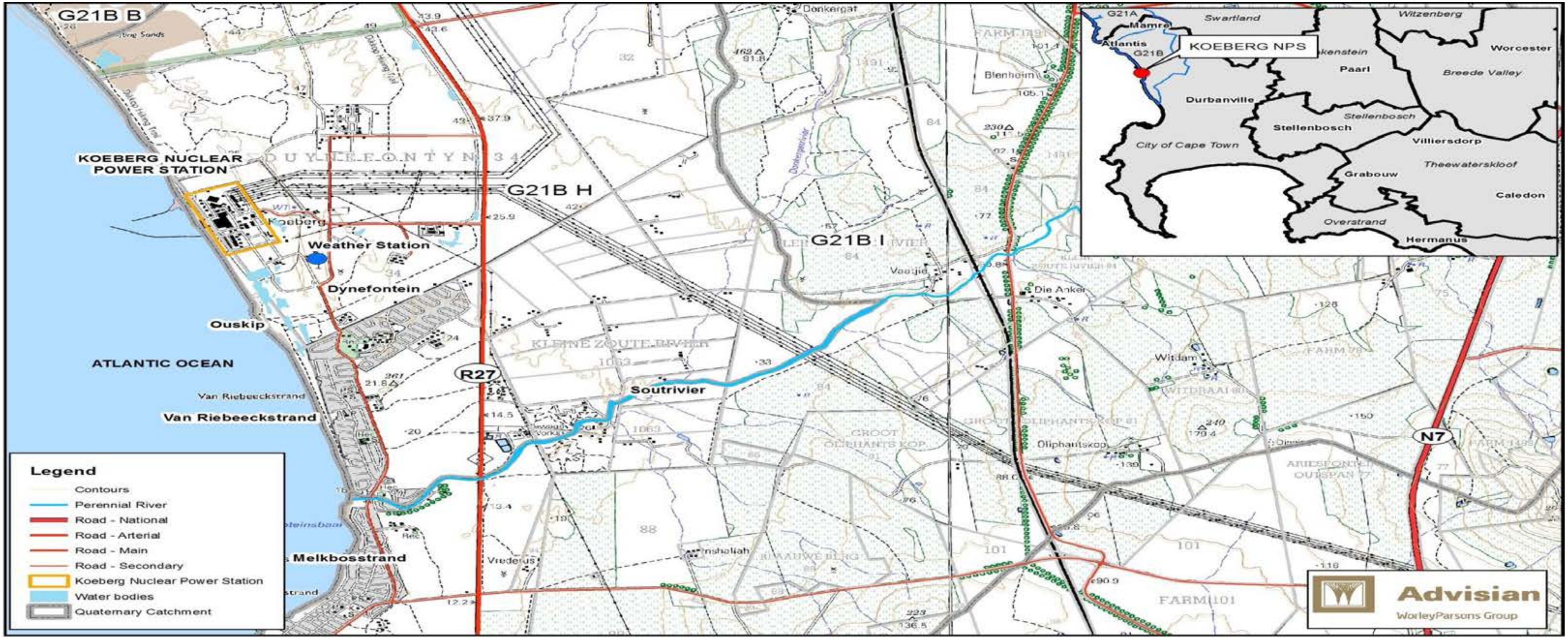

Figure 2: KNPS location

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Figure 3: Site foundation layout and location of the cut-off wall surrounding the nuclear island and turbine hall

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

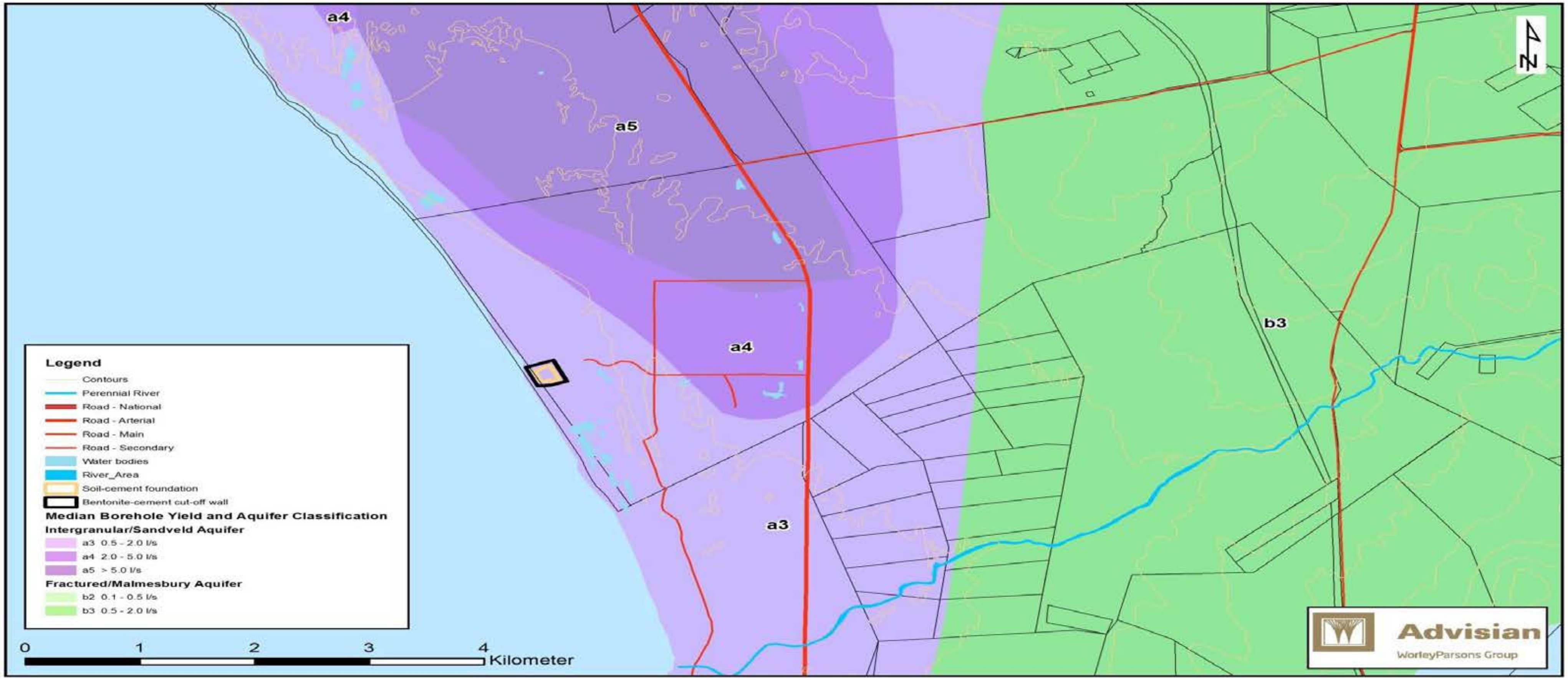

Figure 5: Hydrogeology in and surrounding KNPS

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Figure 6: Groundwater flow in and surrounding KNPS

Appendix C – Conceptual Site Model

Figure 7: KNPS site top view showing locations of cross sections

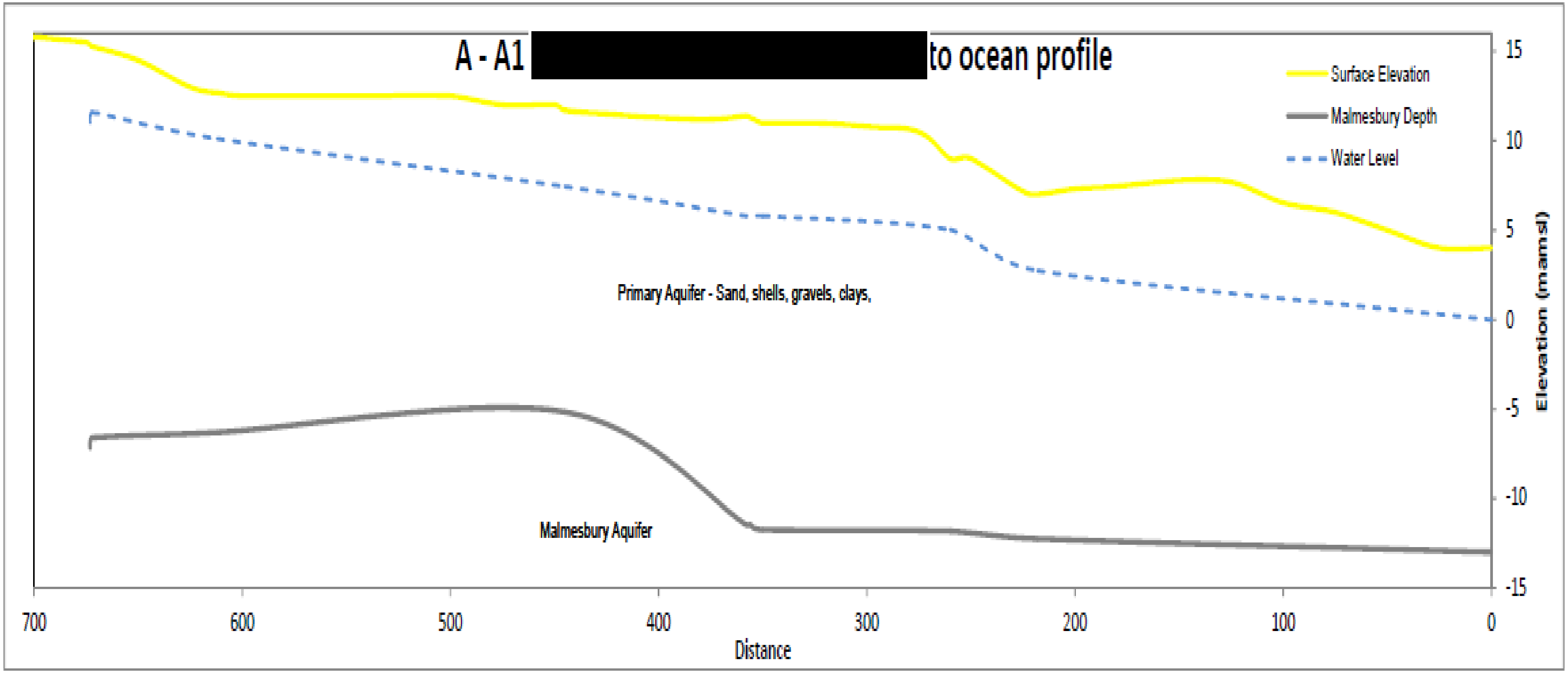

Figure 8: KNPS site cross section A – A1

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

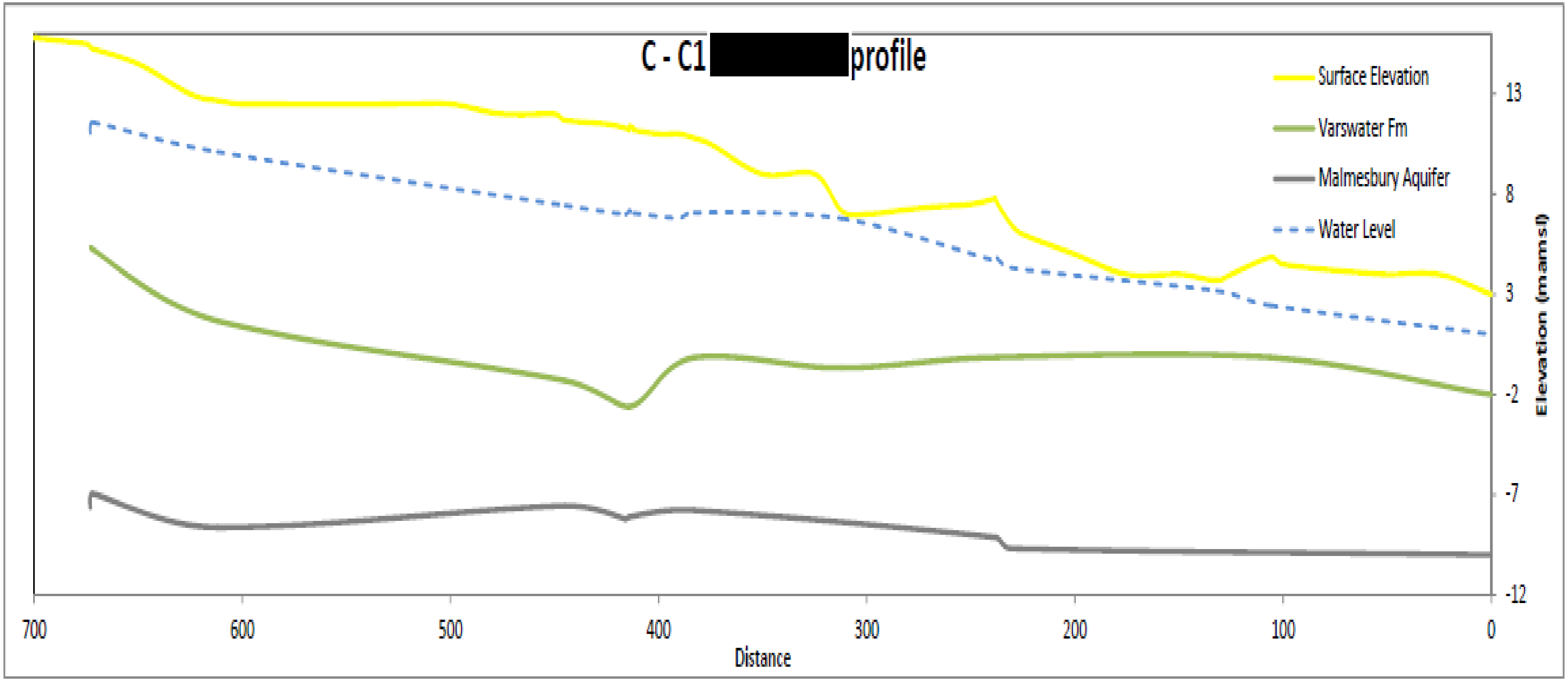

Figure 10: KNPS site cross section C – C1

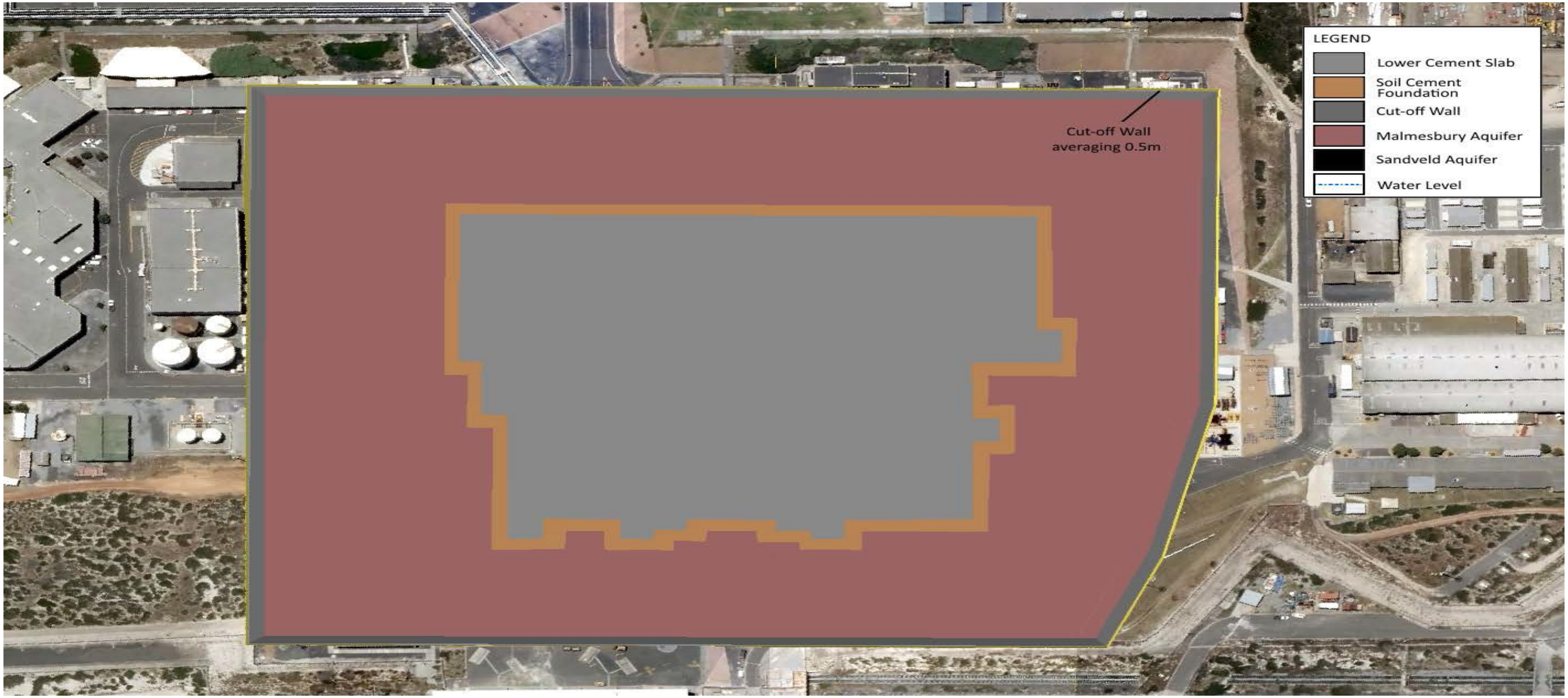

Figure 11: KNPS site schematic model top view

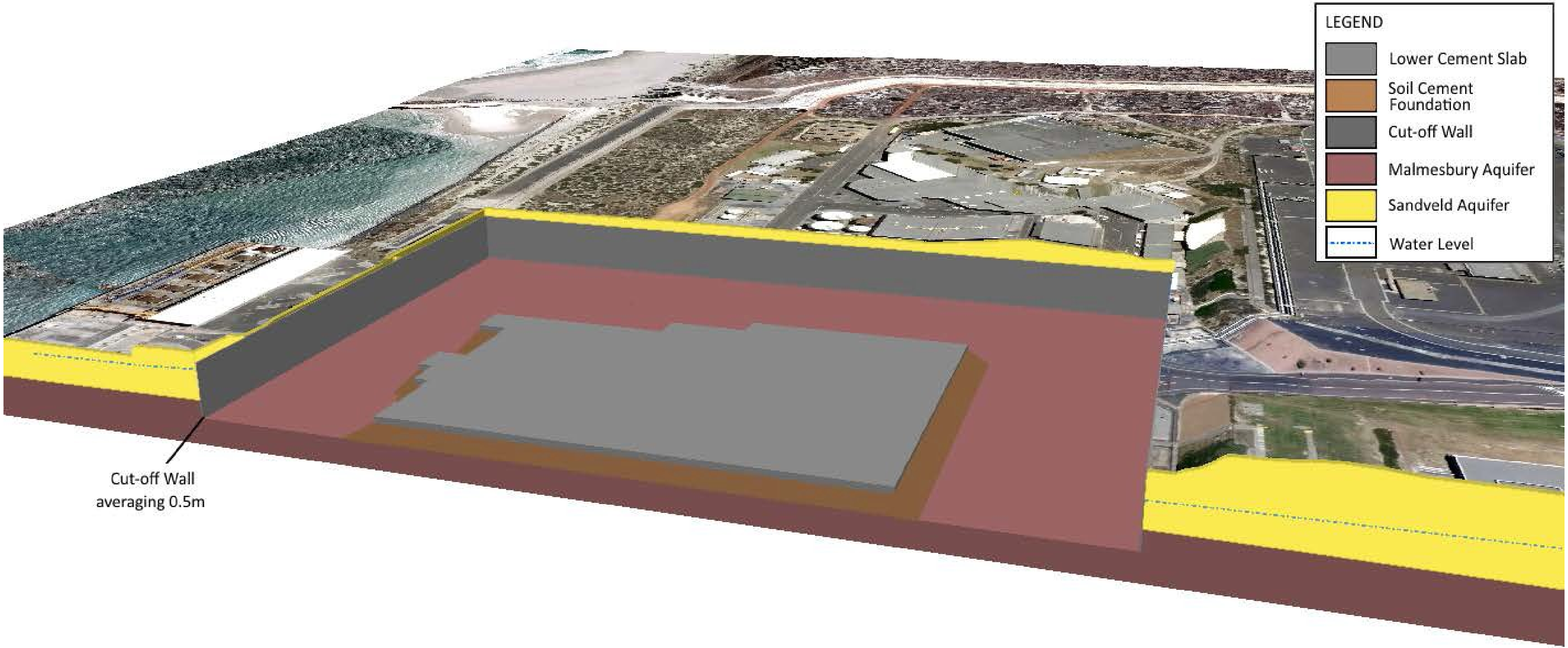

Figure 12: KNPS site 3D schematic model

Appendix D – Numerical Model

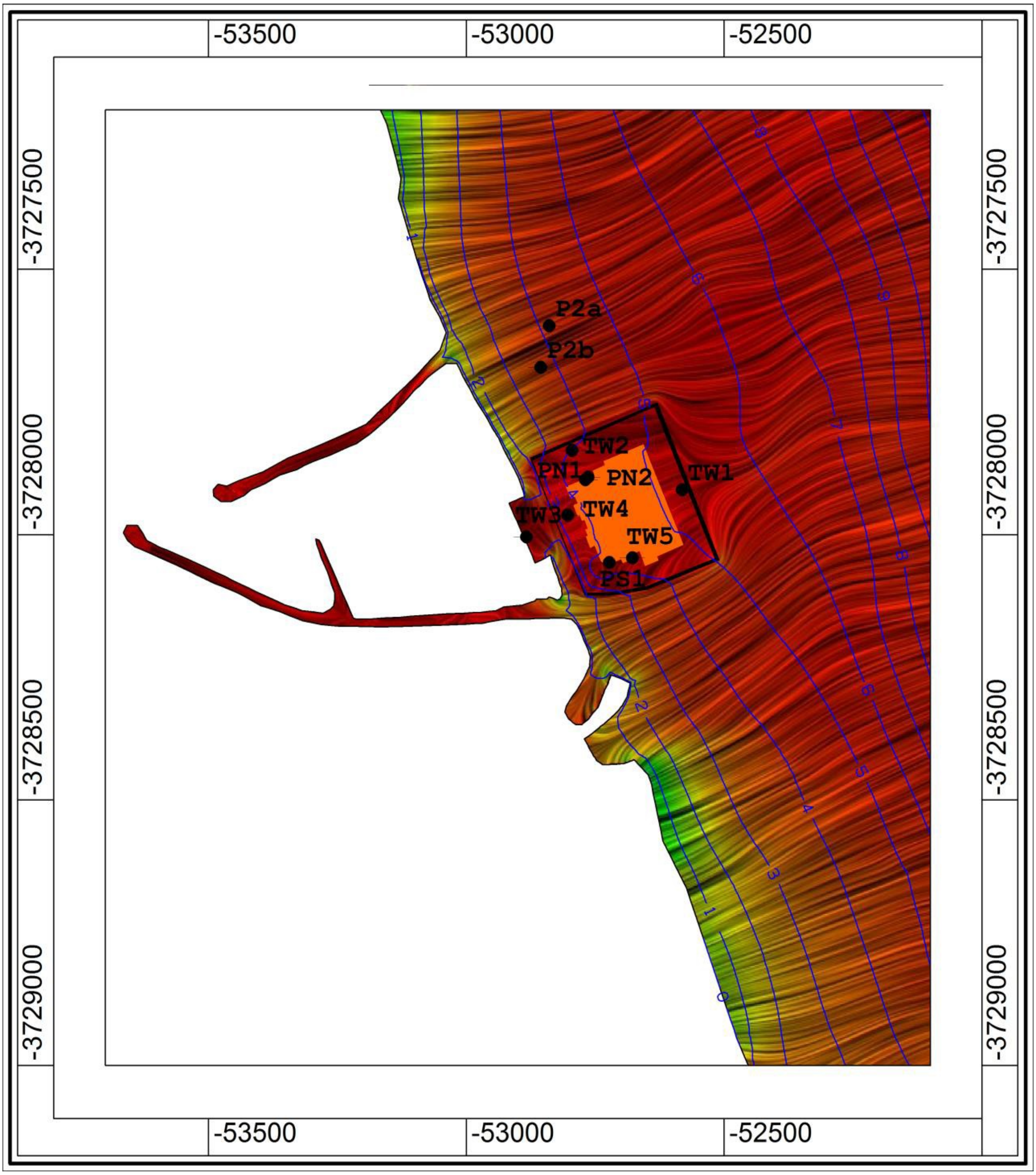

Figure 13: Schlieren illustration of flow velocities in the upper active model layer

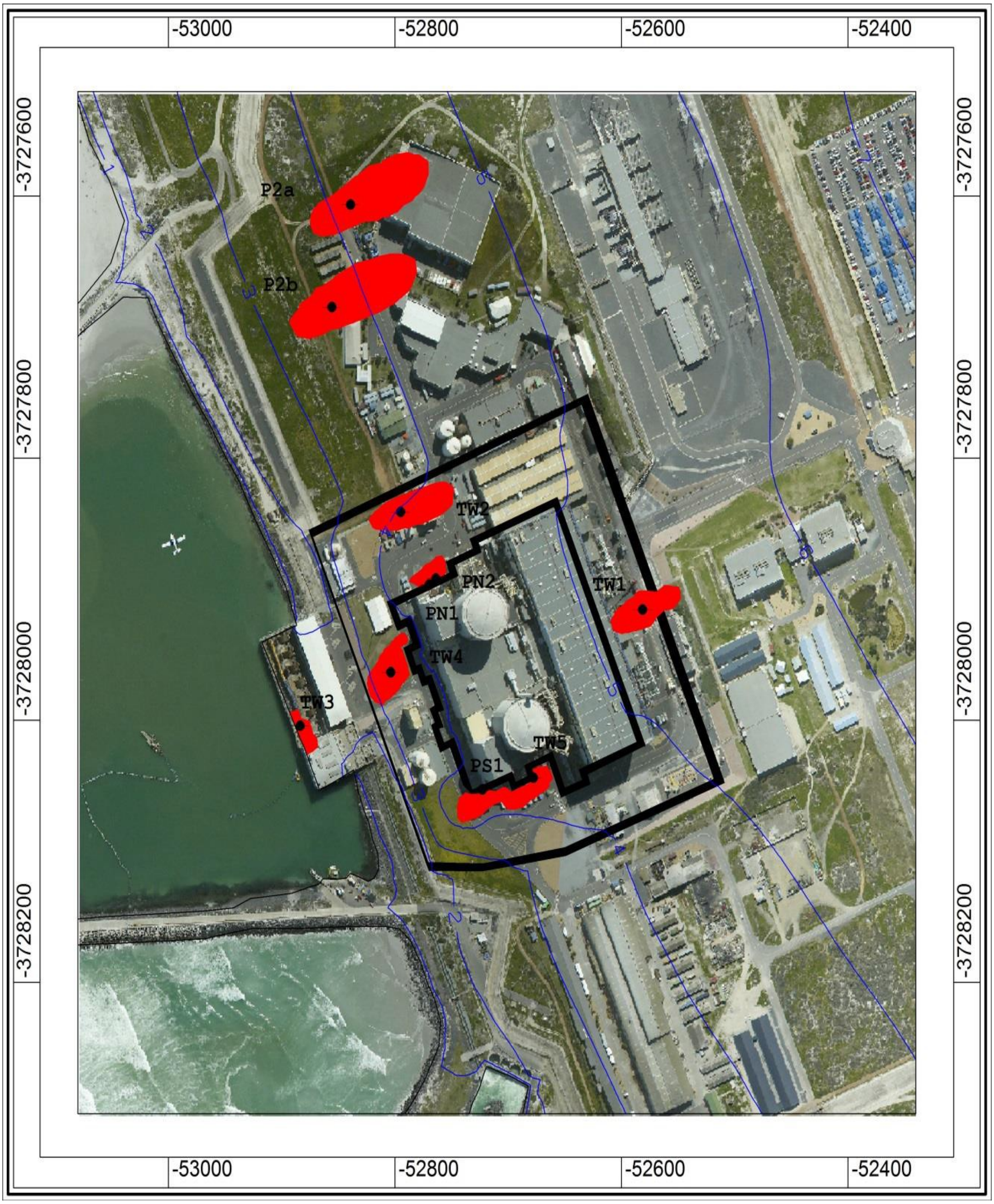

Figure 14: One year capture zones for existing KNPS monitoring boreholes

Appendix E – SEO Contamination Source

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Figure 15: Main SEO catchments

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Figure 16: Effluent discharge areas into the main SEO system

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Figure 17: SEO system sampling locations

NNR ACT, section 47; PAIA section 38(b).Redacted as it contains sensitive information related to the plant layout.

Appendix F – Existing Boreholes

Figure 18: Locations of existing boreholes

Table 4: Existing borehole summary

Borehole	Langelier Index	Langelier/Saturation Index (pH, EC, Ca, $CaCO_3$, TDS, temp)	Cl & SO_4 Corrosion Index	Corrosion Index - aggression
TW1	0.00	Balanced	3.76	<0.1 indicates freedom from corrosion >0.1 indicates progressive corrosion, the higher the value the more aggressive the corrosion
TW2	0.54	Some faint coating	3.95	
TW3	0.35	Some faint coating	10.15	
TW4	1.06	Mild scale coating	0.49	
TW5	0.33	Balanced	1.41	
PS1	0.04	Balanced	8.93	
PN1	4.76	Severe scale forming	1.44	
PN2	3.81	Moderate scale forming	6.43	
P2a	-0.37	Near Balanced	3.12	
P2b	-0.37	Near Balanced	3.43	

Table 5: Existing borehole summary continued

Borehole	Water Level	Chemical Characterisation	Downhole salinity profile	Tritium Activity	Gamma Emitters
TW1	0.76-1.12 mbgl	Na-Cl type moderately saline to saline	fresh water ~ 12.5-14.74 mbgl Mixing ~12.75-15.25 mbgl Saline water14.5-15.m mbgl	Very low <0.5 Bq/l	<1 Bq/l in 2000 & 2009 ^{60}Co <1 Bq/l ^{137}Cs in 2000
TW2	3.9-4.46 mbgl	Na-Cl type with $Ca-CO_3$ character Fresh to moderately saline	fresh water ~ 14.5-15 mbgl Mixing ~14.5-16 mbgl MA 16 mbgl	Very low <0.5 Bq/l	<1 Bq/l in 2000 & 2007 ^{60}Co & ^{137}Cs
TW3	1.17-1.67 mbgl	Na-Cl type Fresh to saline	Mixing of fresh and saline with possible sea water with depth –steady increase in salinity with depth	Variable 2007-2015 low to high 1-11 Bq/l	None detected
TW4	5.72-6.15 mbgl	Na-Cl type with $Ca-CO_3$ character Fresh to moderately saline	Fresh water till 16.25-18.5 mbgl <80 mS/m Mixed water fresh/saline below this >300 mS/m	Very low <1 Bq/l	<1 Bq/l in 2000 ^{60}Co
TW5	3.14-3.88 mbgl	Na-Cl type with $Ca-CO_3$ & SO_4 character Fresh to moderately saline	Fresh water till 15.25-16.5 mbgl <60 mS/m Mixed water to saline below this >300 mS/m	Generally low <2 Bq/l High in 2010 4.8 Bq/l	<1 Bq/l in 2000 ^{60}Co <1 Bq/l ^{137}Cs in 2009 & 2011
PN1	2.97-3.47 mbgl	Na-Cl type with $Ca-CO_3$ character high pH Moderately saline	Steady increase in salinity 300 to 600 mS/m with depth – mixing of fresher water with more saline water	Very low <0.5 Bq/l	None detected
PN2	3.23-3.37 mbgl		Slightly saline water with a slight increase in salinity between 13-14 mbgl	Very low <0.5 Bq/l	None detected
PS1	3.24-3.76 mbgl		Fresher water over whole profile 278-351 mS/m	Moderate to High 2.5-4.2 Bq/l	None detected
P2a	3.16-3.82 mbgl	Na-Cl type Moderately saline	Sandveld aquifer throughout profile 264-291 mS/m	Very low <1 Bq/	None detected
P2b	5.03-5.56 mbgl	Na-Cl type Moderately saline	Sandveld aquifer throughout profile 271-320 mS/m	Very low <1 Bq/ High 6 Bq/l in 2010	None detected

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Appendix G – New Boreholes

Figure 19: New borehole locations (Errata – borehole 27 corresponds to borehole no.1 in Table 11)

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Table 10: Summary of new boreholes for monitoring primary aquifer continued

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Table 11: Summary of new boreholes for monitoring secondary aquifer

NNR ACT, section 47; PAIA section 38(b). Redacted as it contains sensitive information related to the plant layout.

Appendix H – Constituents to be Analysed in Soil and Groundwater

Table12: Soil baseline analyses

Analysis	Locations & rationale
Electrical Conductivity (EC)	All samples. Basic soil quality indicators and indicators of capacity to attenuate contamination.
pH	
Cation exchange capacity	
Total carbonate	
Total organic matter	
Iron (Fe)	
Manganese (Mn)	
Particle size distribution	
Trace Elements	
Arsenic (As)	All samples. Indicators of natural background and contamination from site activities.
Boron (B)	
Cadmium (Cd)	
Chromium (Hexavalent) (Cr^{6+}) and Total Cr	
Copper (Cu)	
Lead (Pb)	
Mercury (Hg)	
Nickel (Ni)	
Vanadium (V)	
Uranium (U)	
Zinc (Zn)	
Radionuclides	
Gamma emitters	All locations (to be confirmed if all analyses possible in soil samples) to be analysed at Koeberg
Hydrocarbon/Organic Contaminants	Locations to be confirmed
Total Petroleum Hydrocarbons (TPH) / Diesel Range Organics (DRO)	
Polycyclic Aromatic Hydrocarbons (PAH)	All samples from near the workshops, oil/fuel storage areas, high voltage transmission and mechanical maintenance areas and other locations with field evidence of contamination. Typical organic contaminants from fuels, oils, solvents, combustion processes.
Volatile Organic Compounds (VOC)	
Polychlorinated biphenyls (PCB)	

Table13: Groundwater baseline analyses

Major Ions	Location	Recommended frequency of sampling
Sodium (Na)	All natural in groundwater, and potential contaminants from chemicals used or stored on site (giving a chemical fingerprint of the water type and characteristics) and effluent from the sewage system.	Baseline analysis to determine outliers, the results will be used to determine what constituents need to be analysed for bi-annual/annual/quarterly monitoring for contaminants (e.g. phosphate) and sewage effluent (e.g. nitrate) and the frequency of analysis
Calcium (Ca)		
Magnesium (Mg)		
Potassium (K)		
Ammonia (NH_4)		
Bicarbonate (HCO_3)		
Chloride (Cl)		
Nitrate & Nitrite as N		
Sulphate (SO_4)		
Phosphorus (P) as orthophosphate (PO_4)		
Minor Ions/Common Dissolved Metals		
Fluoride (F)	Natural constituents of groundwater and from chemicals used on site (e.g. alum or ferric chloride)	Baseline analysis to determine outliers and to determine if routine analyses are required and frequency of analysis
Iron total (Fe)		
Aluminium (Al)		
Manganese (Mn)		
Physio-Chemical Parameters		
Electrical Conductivity (EC) – laboratory and field	All wells. Basic water quality indicators and early warnings of chemical changes.	Baseline analysis to determine outliers and to determine if routine analyses are required and frequency of analysis
pH – laboratory and field		
Total Alkalinity – laboratory		
Total Dissolved solids – laboratory and field		
Dissolved Oxygen (DO) – field		
Dissolved Organic Carbon (DOC)		

Table14: Groundwater baseline analyses continued

Trace Elements		
Arsenic (As)	All wells initially, followed by targeted analysis at wells monitoring the workshops, oil/fuel storage areas, high voltage transmission and mechanical maintenance areas and other locations with unusual concentrations.	Baseline analysis to determine outliers and to determine if routine analyses are required and frequency of analysis
Boron (B)		
Cadmium (Cd)		
Chromium (Hexavalent) (Cr^{6+}) and Total Cr		
Copper (Cu)		
Lead (Pb)		
Mercury (Hg)		
Nickel (Ni)		
Vanadium (V)		
Uranium (U)		
Zinc (Zn)		
Radionuclides		
Tritium	All locations	Baseline analysis to determine outliers and to determine if routine analyses are required and frequency of analysis
Gamma emitters	All locations (to be confirmed if all analyses possible in soil samples) to be analysed at Koeberg	
Hydrocarbon/Organic Contaminants		
Total Petroleum Hydrocarbons (TPH) / Diesel Range Organics (DRO)	All wells initially, followed by targeted analysis at wells monitoring the workshops, oil/fuel storage areas, high voltage transmission and mechanical maintenance areas and other locations with unusual concentrations. Typical organic contaminants from fuels, oils, solvents, combustion processes.	Baseline analysis to determine outliers and to determine if routine analyses are required and frequency of analysis
Polycyclic Aromatic Hydrocarbons (PAH)		
Volatile Organic Compounds (VOC)		
Polychlorinated biphenyls (PCB)		

Appendix I – Acceptance Criteria for Contaminants

Table 15: Acceptance limits for radionuclides

Description	Bq/l
MDA*	≤ 50
Investigation level	200
Maximum allowable limit	10 000

* Applicable to radionuclides: Tritium (H-3), Mn-54, Fe-59, Co-58, Co-60, Zn-65, Ag-110m and Cs-137

Table 16: Acceptance limits for non-radioactive contaminants

Determinand	Unit	Risk	Limit
Microbiological Determinands			
Bacteriological			
Escherichia coli (E. coli)	Count/100mL	Acute Health	Not detected
Faecal coliforms	Count/100mL	Acute Health	Not detected
Protozoan			
Cryptosporidium species	Count/10mL	Acute Health	Not detected
Giardia species	Count/10mL	Acute Health	Not detected
Total coliforms	Count/100mL	Operational	< 10
Heterotrophic plate count	Count/1mL	Operational	< 1 000
Physical and Aesthetic Determinands			
Free chlorine	mg/L	Chronic health	≤ 5
Monochloramine	mg/L	Chronic health	≤ 3
Colour	Pt-Co	Aesthetic	< 15
Electrical Conductivity at 25°C	mS/m	Aesthetic	≤ 170
Total Dissolved Solids (TDS)	mg/L	Aesthetic	≤ 1 200
Turbidity	NTU	Operational	≤ 1
		Aesthetic	≤ 5
pH at 25 C	pH	Operational	≥ 5 to ≤ 9,7
Chemical determinands (macro-determinands)			
Ammonia as N	mg/L	Aesthetic	≤ 1,5
Calcium	-	-	No limit required. Need to measure to characterize water.

Chloride as Cl^-	mg/L	Aesthetic	≤ 300
Fluoride as F^-	mg/L	Chronic health	≤ 1,5
Magnesium as Mg	-	-	No limit required as it contributes to TDS.
Nitrate as N	mg/L	Acute health	≤ 11
Nitrite as N	mg/L	Acute health	≤ 0,9
Nitrite-nitrate ratio	Ratio	Acute health	≤ 1
Sodium as Na	mg/L	Aesthetic	≤ 200
Sulfate as SO_4^{2-}	mg/L	Acute health	≤ 500
		Aesthetic	≤ 250
Zinc as Zn	mg/L	Aesthetic	≤ 5
Chemical determinands (micro-determinands)			
Aluminium as Al	µg/L	Operational	≤ 300
Antimony as Sb	µg/L	Chronic health	≤ 20
Arsenic as As	µg/L	Chronic health	≤ 10
Barium as Ba	µg/L	Chronic health	≤ 700
Boron as B	µg/L	Chronic health	≤ 2 400
Cadmium as Cd	µg/L	Chronic health	≤ 3
Chromium (total) as Cr	µg/L	Chronic health	≤ 50
Cobalt as Co	µg/L	-	-
Copper as Cu	µg/L	Chronic health	≤ 2 000
Cyanide (recoverable) as CN^-	µg/L	Acute health	≤ 200
Iron as Fe	µg/L	Chronic health	≤ 2 000
		Aesthetic	≤ 300
Lead as Pb	µg/L	Chronic health	≤ 10
Manganese as Mn	µg/L	Chronic health	≤ 400
		Aesthetic	≤ 100
Mercury as Hg	µg/L	Chronic health	≤ 6
Nickel as Ni	µg/L	Chronic health	≤ 70
Selenium as Se	µg/L	Chronic health	≤ 40
Uranium as U	µg/L	Chronic health	≤ 30
Vanadium as V	µg/L	-	Not used as a raw material on site. Measurement taken for baseline.
Chemical determinands (organic-determinands)			
Dissolved organic carbon as C	mg/L	-	≤ 25
Total organic carbon as C	mg/L	Chronic health	≤ 10
Trihalomethanes			
Chloroform	µg/L	Chronic health	≤ 100
Bromoform	µg/L	Chronic health	≤ 100
Dibromochloromethane	µg/L	Chronic health	≤ 100

Bromodichloromethane	µg/L	Chronic health	≤ 60
Trihalomethane ratio	Ratio	Chronic health	≤ 1
Total Microcystin as LR	µg/L	Chronic health	≤ 1
Phenols	µg/L	Aesthetic	≤ 10
Free chlorine			
Treatment works	mg/L	Operational	>0 to ≤ 0.5
Points of consumption	mg/L	Operational	>0 to ≤ 0.2
Monochloramine			
Treatment works	mg/L	Operational	>0 to ≤ 0.5
Points of consumption	mg/L	Operational	>0 to ≤ 0.2

Table 17: Acceptance limits for non-radioactive phosphate contaminants

Determinand	**Units (mg/l)**
Ortho-Phosphate as phosphorus	10

Table 18: Acceptance limits for non-radioactive PCB and PAH contaminants

Determinand	**MCGL (mg/L)**	**MCL (mg/L)**	**Potential Health Effects from Long-Term Exposure Above the MCL**	**KNPS Limit (mg/L)**
PCB	0	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	0
Benzo(a)pyrene (PAHs)	0	0.0002	Reproductive difficulties; increased risk of cancer	0

Appendix J – Summary of Programme Tasks

Table 19: Summary of programme tasks

No.	Task Description	Sub-Task Description	Initial	Periodic Frequency
1	Update the risk assessment	Update the conceptual site model	Phase 1, Part 1	Post analysis of sample test results (soil and groundwater)
2				As deemed necessary following review of operating experience
3				When required by the quantitative risk assessment
4		Update the quantitative risk assessment	Phase 2	Every second year during operation
5				Before decommissioned operations are recommissioned
6				When knowledge is obtained regarding new critical receptors
7				As deemed necessary following review of operating experience
8				When new waste facilities are built, waste facilities expanded, contamination is observed through unidentified leakages, large-scale dewatering takes place or when contamination sources are newly delineated. At KNPS, the dry spent fuel storage casks are considered new waste facilities
9	Update the numerical model	-	Phase 1, Part 1	Post analysis of sample test results (soil and groundwater)
10				As deemed necessary following review of operating experience
11	Borehole Construction	Primary aquifer	Phases 2 and 3	Additional scopes to the initial scopes of Phases 2 and 3, as deemed necessary
12		Secondary aquifer	-	During Phase 3, as deemed necessary
13		Primary and Secondary aquifer	Phase 4	As deemed necessary
14		Submit samples for Gamma	Phase 2 – 4	-

		Spectrometry and subsequently submit results to RP to determine RP measures for construction at boreholes suspected to have a potential for radionuclide contamination of concerning levels.		
15	Borehole Maintenance	External visual inspection	Phase 1, Part 1	Quarterly
16		Internal camera inspection (P2a, P2b, PN2, PN1 (partial), TW1 - 2 and TW4 - 5)	Phase 1, Part 2	-
17		Internal camera inspection (All)	-	Every 3 years
18		Repair	-	As deemed necessary
19	Sampling	Groundwater	Phases 2 - 4 and suggested three initial sampling exercises, all within 90 days and not less than 14 days apart	Quarterly and adjusted as deemed necessary
20		Soil	Phases 2 - 4 and suggested three initial sampling exercises, all within 90 days and not less than 14 days apart	As deemed necessary
21	Radiochemical and Chemical Analysis	Comprehensive analysis	Phases 2 - 4 (macro and trace element analysis)	At least every three to five years or as guided by the risk posed and as additionally required by the decommissioning plan (when developed)
22		Indicator analysis	Following Comprehensive Analyses	As deemed necessary until undesirable trends are identified
23	Pollution Source management	Monitoring, reducing and preventing leaks and spills	-	Monthly or as deemed necessary

24		Oversight of leak repairs on plant components and storm water drains	-	Monthly or as deemed necessary
25		Defining temporal impacts profile	Following Quantitative Risk Assessment	As deemed necessary following review of operating experience
26		Removing potential sources of pollution such as hydrocarbon and radionuclide contaminated soils and disposing of such pollution sources at an authorised disposal facility	-	Prior to decommissioning or as deemed necessary
27		Others	-	As deemed necessary
28	Groundwater Remediation	-	-	Prior to decommissioning or as deemed necessary