CHAPTER 5.11: GEOHYDROLOGY		
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EXECUTIVE SUMMARY

Duynefontyn is a brown field site (the site) with two existing reactors of the Koeberg Nuclear Power Station (KNPS) for which extensive geohydrological investigations have previously been carried out. It is also situated adjacent to one of the most well-researched aquifers in South Africa, the Atlantis Aquifer. This extensive pre-existing information has been supplemented with further detailed site-specific geohydrological investigations (hydrocensus, surface geophysics, drilling, packer testing, test pumping) data analysis, monitoring and numerical modelling to produce this section of this Site Safety Report.

On the basis of the results and knowledge gained to date, the following key conclusions are drawn:

- There are two aquifers present at the site, the upper intergranular Sandveld Aquifer and the lower fractured rock Malmesbury Aquifer. The former is a major aquifer to the north and east of the site where it is extensively exploited by the City of Cape Town as a water resource, e.g. the Witzand and Silwerstroom wellfields, supplying the nearby town of Atlantis.

- Groundwater levels are relatively shallow and flow is generally in a westerly to southwesterly direction towards the Atlantic Ocean.

- Rainfall events influence groundwater levels on site with higher levels during winter rainfall periods and lower levels during dry summer periods, but this variance is <1 m seasonally in the site boreholes.

- The monitoring period has coincided with both ‘wet’ and ‘dry’ periods, with 2014 being classed as very wet and the period 2015 to 2018 being classed as a drought, with 2016 to 2017 constituting a severe drought according to the Standardised Precipitation Index method.

- Groundwater quality is moderate with electrical conductivity in most cases <300 mS/m and the groundwater is slightly alkaline to alkaline and of a mixed NaCl and $Ca(HCO_3)_2$ type.

- Extensive use is made of groundwater in the region, both locally on a small-scale and with the town of Atlantis reliant on the two nearby wellfields described above, and the Aquarius Wellfield having been developed in 1996 to supply KNPS.

- Test pumping of the Aquarius Wellfield, located on the site, during the severe drought in 2017 gave similar yields to those when it was first established in 1996. This indicates a buffering effect of the Sandveld Aquifer to climatic extremes, at least in terms of a timespan of a few years, which is attributed to its high porosity and storativity. The yield of this wellfield is 29.5 ℓ/s.

- The shallow water table and saturated and unconsolidated sediments of the Sandveld Aquifer will require dewatering prior to excavations for Nuclear-1

installation foundations, as was done when KNPS was constructed.

- Numerical model simulations indicate potential inflows of *c*.20 ℓ/s into the Nuclear-1 foundation excavations, with a cut-off wall in place and under average recharge conditions. This compares very well with the actual pumping rate required for dewatering of the KNPS foundation excavation, which was 21 ℓ/s. The zone of drawdown should be contained to the site.

- Numerical model simulations for dewatering with a sea level rise of 2.3 m by 2100 and increased recharge translates in to a 4 to 5 m rise in groundwater level at the site and shows higher inflows of up to 27 ℓ/s, with a cut-off wall in place. The zone of drawdown is still confined to the site. However, this scenario is unlikely as Nuclear-1 is scheduled to be constructed long before 2100.

- Dewatering of the Nuclear-1 foundations will not affect the Aquarius Wellfield, and *vice versa*, under all climatic scenarios.

- Contaminant transport scenarios, including a worst-case of a leak over the entire Nuclear-1 footprint with a surrogate 100 per cent concentration source contaminant and with Sr-90 equivalent K_d shows minimal spread after 50 years. Assuming a localised leak from Nuclear- 1 for one month nearest the Aquarius Wellfield also shows very limited spread after 2 and 50 years.

- Groundwater level and quality monitoring since mid-2008 has not shown any anomalous or concerning trends that could affect nuclear safety, apart from the need to cater for corrosive conditions for any construction below the water table.

- Given the Langelier saturation indices for the Sandveld Aquifer groundwater and the coastal environment, use of corrosion resistant materials must be considered in the nuclear installation(s) design

- There are potential long-term issues associated with climate change that could impact site activities, depending on the timing of the latter. Worst-case scenarios were used in the numerical modelling to allow for such events. However, there are limitations on the accuracy of such long-term predictions in terms of both groundwater (input parameter uncertainty, e.g. recharge) and numerical models (simplification of the “real world”).

The investigation and monitoring periods have been relatively long at 13 years and the conceptual and numerical models are considered to be robust and adequate to provide a realistic representation of geohydrological conditions at the site. The KNPS has been operational since 1985 thus providing for a significant period for data gathering and data analysis. The nearby Atlantis Aquifer is also one of the most intensively studied aquifers in the country. However, a key uncertainty is the future impact of climate change on, for example, sea level and site water levels. The numerical flow model will need updating as and when new data or insights are obtained and depending on the timing of site activities in relation to predicted changes in climate and sea level.

AMENDMENT RECORD			
Rev	**Draft**	**Date**	**Description**
0		4 June 2015	NSIP03111. New chapter, replacing old KSSR Rev 0.
1		29 September 2021	Chapter revised to address NNR Comments on TSSR and to align with the latest template on structure and layout of Site Safety Reports.
1a		12 March 2024	Chapter updated to address NNR comment.

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5.11 GEOHYDROLOGY

5.11.1 Introduction

Duynefontyn is a brownfield site (the site) with two existing reactors for which extensive geohydrological investigations have previously been carried out. It is also situated adjacent to one of the most well researched aquifers in South Africa, the Atlantis Aquifer. This extensive pre-existing information has been supplemented with further detailed site-specific geohydrological investigations, data analysis, monitoring and numerical modelling to produce this section of this Site Safety Report (SSR).

5.11.2 Purpose and Scope

The purpose of this section is to document the baseline geohydrological characteristics of the site and surrounding area and carry out numerical modelling to predict future trends under differing climatic scenarios. This is in order to investigate the acceptability of the site for the development of an additional nuclear installation(s) through all stages of its development. This is achieved through detailed data analysis and numerical flow modelling, including scenario modelling, e.g. of reactor foundation excavation dewatering, climate extremes and sea level rise. More specifically this section of this SSR presents:

- aquifers and their hydraulic properties;
- groundwater flow paths;
- groundwater levels and fluctuations, including possible effects of climate change;
- ambient groundwater quality;
- existing groundwater use;
- conceptual groundwater control requirements for the construction and operational phases;
- modelled future changes in the baseline geohydrological system with e.g. climate change and *inter alia* extreme precipitation and sea level rise;
- monitoring results and future monitoring requirements;
- management of uncertainties.

The activities carried out as part of the evaluation of the site and the results achieved are presented in detail in the appendices of this section. These appendices provide the quality assurance record for key decisions and methodologies used and provide the back-up for the data presented herein. Data from this ***Section 5.11*** are used to inform ***Section 5.10*** (Hydrology and Hydraulics), ***Section 5.15*** (Geotechnical Characterisation), sections of ***Chapter 6*** (Evaluation of External Events) and ***Chapter 7*** (Potential Radiological Impact on the Public and the Environment).

5.11.3 Regulatory Framework

The national regulations specifically relevant to a geohydrological investigation for an SSR are The Regulations on Licensing of Sites for New Nuclear Installations (Department of Energy, 2010) and RG-0011 Interim Guidance on the Siting of Nuclear Facilities, Rev 0 (National Nuclear Regulator, 2016). The former regulation is not specific in terms of geohydrology, whereas the latter is and so the references listed below were used to guide the site investigation in terms of the scope of work required:

National

- RG-0011: Interim Guidance on the Siting of Nuclear Facilities, Rev 0 (National Nuclear Regulator, 2016), specifically sections 8.2, Land and Water Use in the Region, 11, Monitoring of Site Conditions – 11.3, Groundwater and Surface Water and Attachment C, Typical Baseline Water Quality Indicators;

- RG-0016: Guidance on the Verification and Validation of Evaluation and Calculation Models used on Safety and Design Analyses, Rev 0 (National Nuclear Regulator, 2016);

- PP-0014: Considerations for External Events for New Nuclear Installations (National Nuclear Regulator, 2012), specifically sections 11.1 (4) Geological and Geotechnical hazards; hydrogeochemical effects, and 11.4 (5) Precipitation; Dispersion of releases from the NNP through surface water of groundwater, and Appendix G;

- Eskom's Technical Specification for Site Safety Reports, NSIP01388 (Rev 0). Section 5.11: Geohydrology (Eskom, 2010).

International

- United States Nuclear Regulatory Commission (US NRC), NUREG-0800, Section 2.4.12 Groundwater, Rev. 3 (United States Nuclear Regulatory Commission, 2007);

- US NRC, Regulatory Guide 1.132, Site Investigations for Nuclear Power Plants, Rev. 2 (United States Nuclear Regulatory Commission, 2003);

- International Atomic Energy Agency (IAEA) Safety Requirements

No. SSR-1, Site Evaluation for Nuclear Installations (International Atomic Energy Agency, 2019). Relevant sections include description of the main water bearing formations, determination of the dispersion of radioactive material through groundwater, groundwater use in the region and monitoring;

- IAEA Safety Guide No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants (International Atomic Energy Agency, 2004). Section 2 (2.3, 2.8, 2.12, 2.19) covers characterisation of the groundwater regime and section 7.5 details monitoring requirements;

- IAEA Safety Guide No. NS-G-3.2, Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluations for Nuclear Power Plants (International Atomic Energy Agency, 2002). Sections 3.5 to 3.6 deal with normal and accidental discharge to surface water and groundwater; sections 3.7 to 3.11 deal with surface and groundwater monitoring and sections 3.24 to 3.39 deal with groundwater considerations or data required to classify the groundwater regime.

5.11.4 Approach to Evaluation

The site incorporates the existing Koeberg Nuclear Power Station (KNPS), units 1 and 2, for which extensive geohydrology/hydrology investigations were carried out during the 1970s, with follow-up groundwater level and quality monitoring over the entire Duynefontyn site. Further geohydrological work was conducted at the KNPS and its surrounds in the 1990s, including investigations for additional local potable water supplies. These investigations led to the development of the Aquarius Wellfield to the northeast of the KNPS. A SSR (the ‘KSSR’) was produced for the existing KNPS, which included a section on geohydrology (Eskom, 2006). Three revisions were produced of which Rev 0 is the version approved by the National Nuclear Regulator (NNR).

Geohydrological work was also carried out for the proposed Pebble Bed Modular Reactor Demonstration Power Plant (PBMR DPP) during 2000 (Council for Scientific and Industrial Research, 2000) and 2001 (Council for Scientific and Industrial Research, 2001), and a groundwater monitoring programme was initiated during February 2008 (SRK Consulting, 2010). A groundwater flow simulation model was developed to provide information on likely scenarios of groundwater level and groundwater quality changes during dewatering for construction of the PBMR nuclear island foundations (Council for Scientific and Industrial Research, 2000). A specialist water study was also carried out for both the first and second Environmental Impact Assessments (EIAs) for the planned PBMR DPP (Africon, 2000) and (SRK Consulting, 2007). However, the PBMR project was cancelled in 2010.

The above reports combined site data with extensive geohydrological reports and data on the Atlantis area. This latter work centres around investigations into the Atlantis Aquifer (a specific part of the Sandveld Aquifer, see ***Subsection 5.11.7.1***), one of the most studied aquifers in South Africa and which underlies most of this SSR study area, including the site. Some of the references cited may appear to be out of date but the geohydrological principles, conceptualisations and parameters so derived have been assessed by the authors and, where found to be still valid, have been incorporated into this study.

Drawing 5.11.1 shows the site boundaries, the KNPS, enveloping footprint for the new nuclear installation(s) and illustrative nuclear installation footprint in the context of the local and regional physiographic setting. The illustrative Nuclear-1 footprint represents a possible site for the terrace where the new nuclear reactors and main auxiliary buildings would be situated. The results of the meteorological (see ***Section 5.8***), hydrological (see ***Section 5.10***), geological (see ***Section 5.13***) and geotechnical (see ***Section 5.15***) studies were taken into consideration in the preparation of this section. Close liaison was maintained with the specialists carrying out these parallel studies to ensure commonality of approach and data use where appropriate, to avoid duplication of work and ensure agreement on areas of joint interest, e.g. borehole siting.

In order to meet the requirements of ***Subsection 5.11.2***, the approach to the investigation broadly comprised the following:

- **desk study**: detailed review and collation of available information; georeferencing of data; liaison with geotechnical and geology/seismic consultants; site reconnaissance; selection of provisional exploratory borehole sites; liaison with Eskom Nuclear Siting Studies Team; formulation of Integrated Management System, Risk Assessment, Health and Safety Plan, Method Statement and client approval thereof; drawing up tenders for drilling, test pumping and packer testing, advertising, adjudication and award; appointment of health and safety consultant for site work;

- **field work**: hydrocensus; selection and verification of borehole sites in consultation with Eskom and the geological, seismic and geotechnical specialists; selection and verification of drilling techniques; drilling of exploratory/test/monitoring boreholes; down-hole camera surveys; test pumping; packer testing; chemical, isotope and radiological analysis of water samples; sorption tests on soil samples; set up and implementation of a monitoring network;

- **data analysis**: determination of aquifer parameters; construction of a 3D conceptual geohydrological model; selection of a suitable software code for numerical flow modelling and numerical flow and scenario modelling;

- **reporting**: writing the Geohydrology section of the SSR.

Specific activities carried out were:

- review of available information and in particular reports, maps and data for the KNPS and PMBR DPP sites, and from the Geological Survey and the Department of Water Affairs and Forestry (DWAF)[1], e.g. borehole information in the National Groundwater Archives, NGA (see ***Appendix 5.11.A***);

- study and interpretation of air photographs and satellite imagery;

- field surveys (hydrocensus) in late 2007 and again in August 2017, of representative boreholes and springs not already covered by previous surveys and collation of data from previous work (see ***Appendix 5.11.B***);

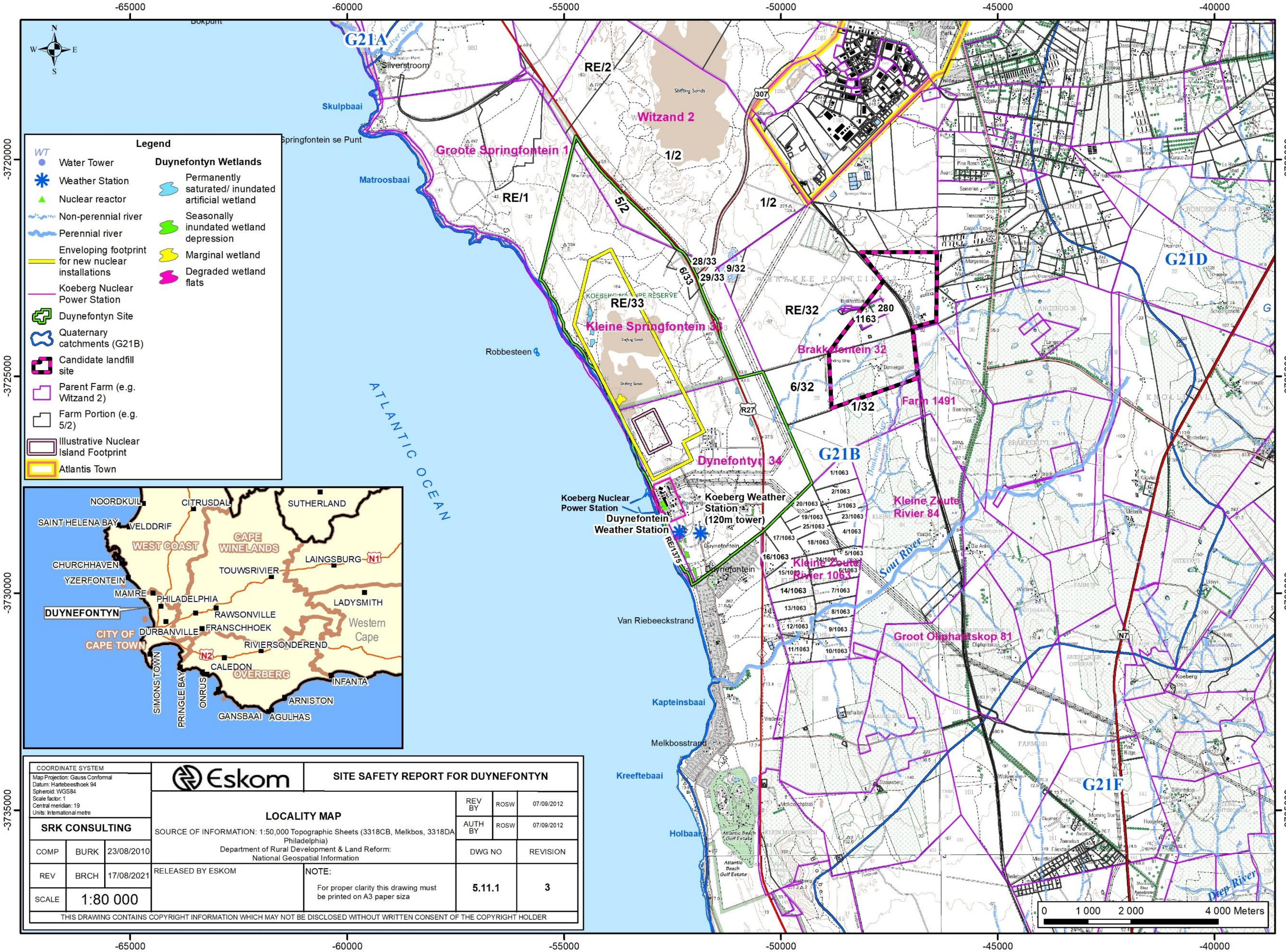
- site reconnaissance, surface geophysics and discussions with the Council for Geoscience (CGS), SSR geotechnical consultants and Eskom Nuclear Sites in support of the location of exploratory, test and monitoring boreholes (see ***Appendix 5.11.C***);

- drilling of 12 new boreholes within the site boundaries, concentrating on the provisional enveloping nuclear installation footprint area[2] and illustrative nuclear terrace/footprint area close to the coastline (see ***Appendix 5.11.D***). The extensive drilling programme carried out for the geotechnical investigation (see ***Section 5.15***) was also taken into account;

- implementation of a testing programme including yield tests, down-hole camera survey and packer testing on selected new exploratory boreholes to obtain additional information on aquifer hydraulic properties of the site (see ***Appendix 5.11.E***).

[1] Correct name for early-source data, now known as the Council for Geoscience and Department of Human Settlements, Water and Sanitation, respectively.

[2] Provisional area where the nuclear installation(s) and auxiliary infrastructure are likely to be located.



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- laboratory testing, including macro, trace, isotope and radionuclide analyses of groundwater samples obtained from the hydrocensus and exploratory holes to determine chemical, approximate age and origin characteristics of the groundwater (see ***Appendix 5.11.F***, ***Appendix 5.11.G*** and ***Appendix 5.11.H***);

- georeferencing and incorporation of all relevant data into a geographical information system (GIS) for spatial analysis;

- adsorption testing on soil samples, to determine the partition coefficient of certain radionuclide species within the aquifers occurring on site at different pH values to give an indication of retardation of such species within the aquifer for numerical modelling purposes (see ***Appendix 5.11.I***);

- development of a conceptual site model and then numerical flow modelling to replicate site and surrounding catchment area conditions to an acceptable level (as indicated by calibration and sensitivity analysis) and then carrying out simulation of scenarios such as climate change (extreme precipitation and sea level rise), dewatering of the nuclear installation foundations, contaminant transport and groundwater control measures (see ***Appendix 5.11.J*** for the numerical model validation and verification reports which include a description of the model setup, parameterisation, calibration, sensitivity testing, assumptions and limitations);

- initial (for this SSR) and ongoing monitoring programme to provide baseline groundwater level and quality data (see ***Appendix 5.11.F***, ***Appendix 5.11.G*** and ***Appendix 5.11.H***);

- drilling of a further three investigative/monitoring boreholes around key wetland areas and installation of three shallow piezometers within the wetlands in early 2010 (see ***Appendix 5.11.D***). These boreholes/piezometers were incorporated into the SSR monitoring network (SRK Consulting and Freshwater Consulting Group, 2011) and ***Appendices 5.11.F***, ***5.11.G*** and ***5.11.H***).

The results of the above activities were used to inform numerical flow modelling to simulate scenarios such as dewatering of the nuclear installation foundations, fluctuations in groundwater levels (particularly under climate change influences), contaminant transport and groundwater control measures (see ***Appendix 5.11.J***). These are the key site nuclear safety issues from a geohydrological perspective. The main sources of information used in compilation of this section are referenced in the text and listed under ***Subsection 5.11.12***. The geohydrology is first discussed at the regional scale and then the site-specific scale.

5.11.5 Regional Geohydrology

The topography is relatively flat with a gentle slope towards the coast. However, both Quaternary-age (<3 Ma) dunes stabilised by vegetation and Recent-age unconsolidated dunes with heights of <10 m above mean sea level (m amsl) are found along the coastline. No river channels drain the immediate site. However, the Sout and Diep rivers drain the broader areas within the study area (20 km radius around the site). The Donkergat River is a tributary of the Sout River (see ***Drawing 5.11.2***). These rivers all flow in a southwesterly direction towards the coast. These rivers are generally ephemeral in nature and only flow for short periods after significant rainfall events. Based on the nature of these rivers, it has been postulated that groundwater does not discharge into the rivers in the site area (Parsons and Associates, 2006). This is discussed further under numerical modelling in ***Subsection 5.11.7***. Most of the smaller streams 'disappear' in the flat sandy areas near the ocean and/or cannot maintain open river channels across the narrow, raised dunes along the coast.

The site has a Mediterranean climate characterised by warm, dry summers and mild, moist winters. The mean annual precipitation (MAP) measured at the Koeberg weather station (see ***Drawing*** 5.11.1) from 1980 to 2019 is 372.1 mm. Maximum rainfall occurs during June (65 mm), July (68 mm) and August (53 mm), while the lowest rainfall occurs during January (10 mm) and February (8 mm). Extreme values for the site, as referenced from ***Section 5.8***, are defined as follows:

- 'High' rainfall - 23.7 mm/h, 70.0 mm/24 h and 162.4 mm/month. On this basis, 1986 to 1988 and 2013 to 2014 were 'wet' periods, with 1987, 1988 and 2014 being very wet;

- a drought is traditionally defined in South Africa as a year in which the rainfall is 75 per cent or less than the average taken over a 30-year period. However, the South African Weather Services use the internationally accepted Standardised Precipitation Index or SPI. A drought occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. On this basis, the frequency of a moderate drought is 15.8 per cent, a severe drought 6.8 per cent and an extreme drought 2.8 per cent. Accordingly, 2015 to 2018 can be described as a drought, with 2016 to 2017 being a severe drought. Wet and drought periods are illustrated in ***Figure 5.11.12***.

- Rainfall is measured at other stations in the surrounding area/region by the South African Weather Services and used in the evaluation of the MAP for the catchment. That for the Wesfleur station in Atlantis (see ***Drawing 5.11.14***) is 453.3 mm for the period 1979 to 2010 (as provided by the South African Weather Service). This is considerably higher than that recorded at the site and is attributed to the station being situated at a higher elevation, and has been taken into account in the regional flow modelling described in ***Subsection 5.11.7***. With wet and dry periods being experienced in the period 2011-2020, using the period 1980-2020 would not have made a significant difference to this MAP, had the data been available. Rainfall probabilities for 1 in 100 year and 10^{-8} MAP have also been incorporated into the scenario modelling.

5.11.5.1 Geology

The geology of the area is shown in ***Drawing 5.11.2*** and is detailed in (Geological Survey, 1984) and (Geological Survey, 1990), in ***Section 5.13***.

The site and surrounding area are underlain by rocks of the Malmesbury Group, with outcrops along the coast. The Malmesbury Group is overlain by varying thicknesses of calcified and mostly unconsolidated sediments, primarily of the Sandveld Group, which is itself overlain by narrow strips of alluvium along the river channels mentioned above and/or soil.

The Sandveld Group comprises six formations of fluvial, estuarine, shallow-marine and aeolian origin sediments of Cenozoic (Miocene to Late Pleistocene) age (<65 Ma) (Geological Survey, 1984). The thickness of the various formations of the group varies considerably and reaches a maximum of between 40 and 70 m, at Witzand. The various formations and lithologies are listed in ***Table 5.11.1***. Drilling operations for this SSR indicate that the sediment thickness beneath the site ranges from 14 to 27 m.

The late Precambrian-age (*c*.560 Ma) Malmesbury Group comprises metasediments belonging to the Tygerberg Formation. This formation consists mainly of interbedded greyish, fine to medium grained greywacke, phyllitic shale, siltstone and impure quartzite with minor impure limestone and tuff beds (Geological Survey, 1984) and (Geological Survey, 1990). These rocks are baked to a massive bluish-grey hornfels along the contact zone with the intrusive Cape Granite Suite (not cropping-out on the site) and along narrow dolerite dykes.

The Malmesbury Group underlying the site comprises a steeply dipping (up to 60°), interbedded, laminated succession of greywacke, siltstone and mudstone, with occasional shale beds (Johnson, et al., 2006). Gradational successions and contacts are characteristic, and the beds are upward-fining. These rocks are highly weathered within the upper 10 m, with an average of 3.7 m of residual clayey silt being observed during previous (Eskom, 2006) and new SSR drilling at the site. The bedrock shows near upright to southwest verging folds and is intensely jointed resulting in a slatey cleavage. It is brecciated along fault zones and is often sheared along such fault planes. The properties of these fault zones and implications for site suitability are discussed in ***Section 5.13*** and are summarised briefly here. Northwesterly trending faults are characterised by axial plane fracture cleavage and are frequently displaced by east and northeast trending faults. Numerous open fractures, tension gashes and joints are visible in outcrops along the coast. There are no dykes in the footprint area but aeromagnetic and ground magnetic surveys show a west-northwest to east-southeast trending swarm of dolerite dykes in the southern portion of the site (see ***Section 5.13***).

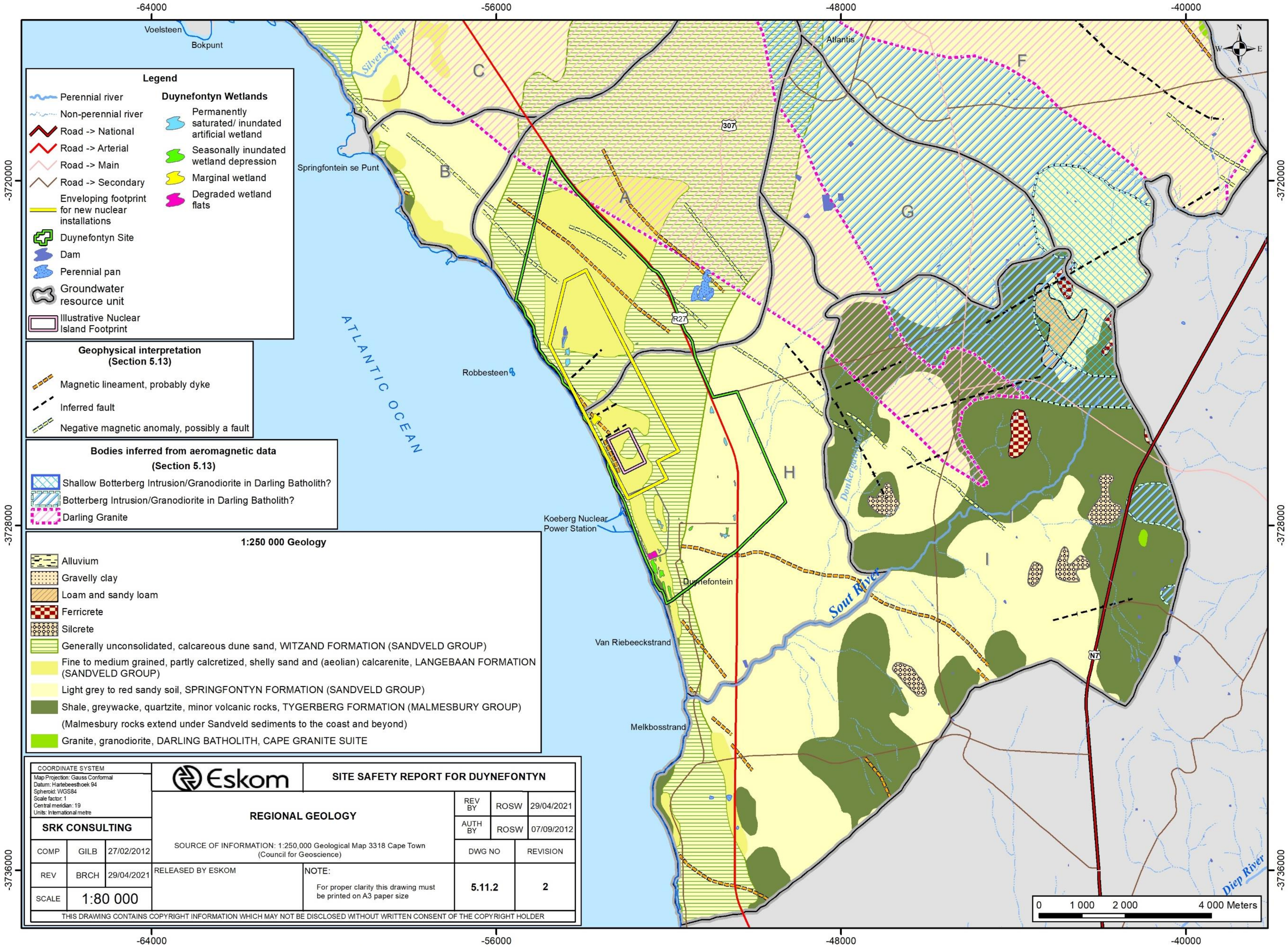
5.11.5.2 Aquifer Types

The site overlies two aquifer systems, namely the southern extent of the upper-lying primary or intergranular Sandveld Aquifer and the deeper-lying weathered and fractured-rock (secondary) aquifer system of the Malmesbury Group (see the schematic hydrogeological cross-section depicted in ***Figure 5.11.23***). The intergranular aquifer is known locally as the Atlantis Aquifer and is one of the most studied aquifers in South Africa.

Virtually all groundwater production boreholes draw from the well-sorted, fine to medium grained quartz sand horizons of the upper Springfontyn Formation as it is usually the thickest formation present. The thickness of the primary aquifer at the site is between 14 and 27 m and the rest groundwater level occurs between 2 to 5 m below ground level (m bgl). The results of previous drilling at the KNPS indicate a profile of 3.0 to 4.5 m of slightly calcareous sand which becomes organic-rich and contains shell fragments below 7.5 m (Eskom, 2006). The lower part of the primary aquifer consists of pebbly sand grading into gravels. This profile also occurs surrounding the proposed PBMR DPP site (Council for Scientific and Industrial Research, 2000). This profile has been confirmed to be extensively developed over the site by this SSR drilling programme (mud-rotary method through the upper sand layers and then rotary-percussion in the bedrock).

Table 5.11.1
Lithostratigraphy: Sandveld Group

Formation	Member	Origin	Type	Description	Epoch
Witzand		Aeolian	Sand	Fine- to medium-grained, whitish grey to slightly reddish, calcareous, cross-stratified, partly vegetated mobile calcareous dune sands containing snails, echinoid spicules, forams and comminuted sea shells	Holocene 0.01 to 0 Ma
Springfontyn		Aeolian	Sand	Fine- to medium-grained, reddish to grey quartz, muddy and peaty in places	Pleistocene to Holocene 1.8 to 0.01 Ma
Langebaan		Aeolian	Calcrete and sandstone	Cross-bedded, fine- to medium-grained, with calcrete layers	Late Pliocene to Late Pleistocene 2 to 0.2 Ma
Velddrif		Shallow marine	Gravel and sand	Partially consolidated, shelly and pebbly, cross-bedding	Pleistocene to Late Pleistocene 1.8 to 0.2 Ma
Varswater	Muishond Fontein	Estuarine/ shallow-marine	Sand	Phosphatic, quartz-sand	Miocene to Pliocene 23 to 5 Ma
	Langeberg	Estuarine/ shallow-marine	Sand	Non-phosphatic, carbonaceous clay and lignite lenses	Miocene to Pliocene 23 to 5 Ma
	Konings Vlei	Shallow-marine	Gravel	Pebbles and cobbles	Miocene to Pliocene 23 to 5 Ma
	Langeenheid	Estuarine	Sand	Argillaceous (clayey sand/silt)	Middle Miocene 14 Ma
Elandsfontyn		Fluvial	Sand and gravel	Angular clasts, Carbonaceous, clay and lignite lenses	Early to Middle Miocene 23 to 14 Ma
Ma = Million annum					



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The Malmesbury Aquifer, which is a secondary aquifer is a semi-confined system that is in hydraulic connection with the overlying primary aquifer. Interpretation of previous pumping test results supports the hypothesis that upward leakage from the secondary to the primary aquifer can be expected if the water table in the latter is drawn-down below the piezometric level in the underlying semi-confined aquifer (Council for Scientific and Industrial Research, 2000). These two aquifers are generally separated by a zone of weathered bedrock (clay). The clay horizon constitutes an aquitard, as it has a low permeability but high storage potential; it retards but does not prevent the movement of groundwater. The areas east and further inland of the site have outcrops of the Tygerberg Formation of the Malmesbury Group and comprise phyllitic shale and impure sandstones (greywacke) that weather to produce substantial thicknesses of yellow and/or grey clay.

The Atlantis Aquifer is a major primary aquifer with three production wellfields, namely the Witzand and Silwerstroom wellfields (both owned by the City of Cape Town - CCT) and the Aquarius Wellfield (owned by Eskom), tapping it. In the Aquarius and Witzand wellfields the nearest boreholes are located 1.2 and 3.0 km northeast of the illustrative nuclear installation footprint centroid, respectively. The former wellfield supplies water to the site (for game watering currently but potentially also for a desalination plant at the KNPS) whilst the latter supplies Atlantis. Similarly, the Silwerstroom Wellfield is located 9.7 km north-northwest of the centroid and also supplies Atlantis. There are also many other existing privately-owned boreholes/wellpoints in the area.

The regional groundwater regime at and surrounding the site is detailed on the DWAF 1:500 000 Hydrogeological (DWAF terminology) Map (Department of Water Affairs and Forestry, 2000) and accompanying booklet (Department of Water Affairs and Forestry, 2001). The DWAF aquifer classification is shown in ***Drawing 5.11.3***. The details on the DWAF map have subsequently been updated and more specific information added to this SSR as a result of the geohydrological and geotechnical drilling programmes implemented at the site from late 2007 to 2010 and geohydrological information gathered from reference sources and work done for the KSSR prior to 2008.

On the basis of the DWAF (Department of Water Affairs and Forestry, 2000), (Department of Water Affairs and Forestry, 2001) and SSR work, the following regional characteristics pertain to the fractured rock aquifer within the Malmesbury Group:

- groundwater potential is generally low due to the dominant fine-grained argillaceous (clay/mud) lithology, lack of coarser grained interbedded arenaceous units and structural complexity and deformed (highly jointed) nature of this aquifer;

- areas of greater groundwater potential include areas overlain by the Sandveld Aquifer, contacts with granite intrusions, the unconformity between the Malmesbury and Table Mountain Group (TMG), where faults and joints extend from adjacent/overlying TMG into the underlying Malmesbury Group and in joints, fractures or bedding planes in interbedded grits and sandstones occurring in the Malmesbury Group;

- sustainable borehole yields are variable, being mostly <2 ℓ/s, but with higher yielding boreholes of >2 ℓ/s where the Sandveld Aquifer is present and from granite or TMG contacts or discrete fractures;

- springs are rare and occur in contact with granite or the TMG in deep-seated faults, which extend into the underlying Malmesbury rocks;

- groundwater chemistry varies considerably due to variations in lithology but is generally of a sodium-chloride and alkaline type;

- direct rainfall recharge predominantly occurs inland in higher-lying outcrop areas;

- on a regional scale, this aquifer is classified as a minor aquifer of moderate to low vulnerability (Council for Scientific and Industrial Research, 1995);

- groundwater flow direction is predominantly to the west, with flow from higher elevations and discharge into the Atlantic Ocean.

On the basis of the DWAF (Department of Water Affairs and Forestry, 2000), (Department of Water Affairs and Forestry, 2001) and SSR work the following regional characteristics pertain to the Sandveld Aquifer:

- it is a major aquifer of high vulnerability (Council for Scientific and Industrial Research, 1995);

- it shows high storage capacity (>15 per cent) and good groundwater supply potential (median borehole yield of >5 ℓ/s);

- the aquifer extends to below sea level in places and is thus vulnerable to saline-water intrusion in coastal areas should over-abstraction occur;

- the available groundwater storage exists mainly in the sands and aeolianite, with most of the groundwater flow occurring in the pebble/gravel and shell beds;

- recharge percolates rapidly through the highly porous, fine sandy and calcareous material to the pebble/gravel/shell beds towards the base of the succession;

- minor dune-slack wetlands occur parallel to the coastline and are seasonal due to water table fluctuations;

- the Silwerstroom Spring occurs northwest of Atlantis, discharges into the Atlantic Ocean and has a yield of 16 ℓ/s. There are also a few non-perennial streams that follow poorly defined canals or seep into the sand;

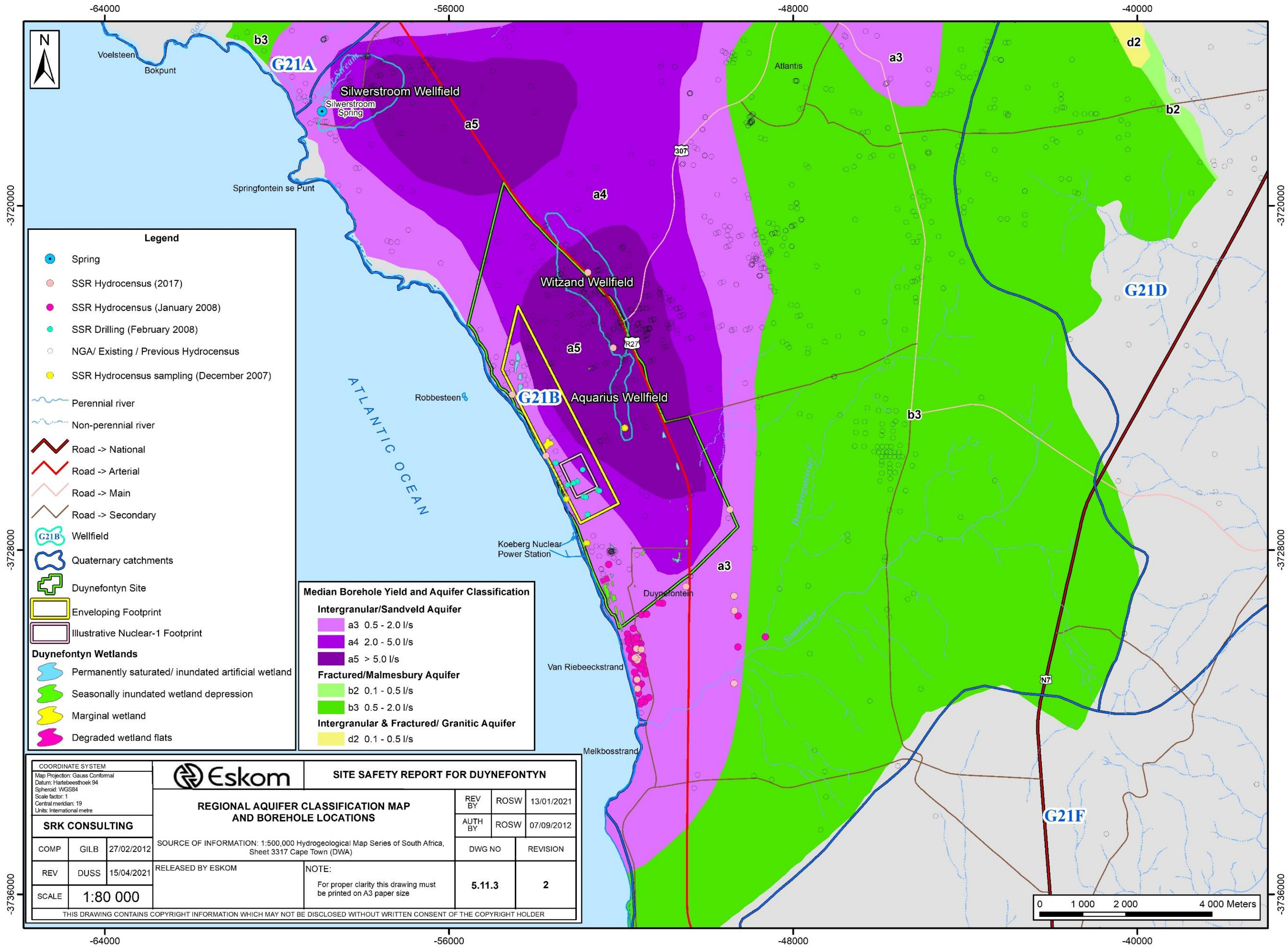
- build-up of groundwater levels is unlikely to occur because of the high porosity and hydraulic conductivity of the Sandveld Group formations (see ***Subsection 5.11.5.6***). The weakly constrained discharge of groundwater in to the nearby ocean means that water levels are readily dissipated;

- groundwater flow direction is to the west with discharge into the coastal zone;

- borehole yields are typically 0.1 to 5.0 ℓ/s and groundwater levels are between 2 and 5 m bgl. Some much higher yields of up to 88 ℓ/s have been obtained from boreholes in the thickest part of the Atlantis Aquifer.

5.11.5.3 Regional Groundwater Recharge

The site falls within quaternary catchment G21B. The Duynefontyn study area extends from the edge of the Atlantis industrial area southwards to the Sout River near Van Riebeeckstrand. The western and eastern boundaries of the study area are formed by the coastline and outcrops of the Tygerberg Formation rocks, respectively. The study area is predominantly covered by geologically young and unconsolidated sediments (***Drawing 5.11.4***).



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Recharge Estimated from Mean Annual Precipitation

Numerous estimates of recharge, as a percentage of MAP, in the vicinity of the site have previously been made (Department of Water Affairs and Forestry, 1982), (Council for Scientific and Industrial Research, 1990) and (Council for Scientific and Industrial Research, 1992). Recharge was thus estimated to be between 15 and 42 per cent of MAP, with MAP equal to 450 mm (at Wesfleur, not the site). The wide range of recharge is attributed to differences in vegetation cover in different parts of the study area, from unvegetated, mobile dunes to vegetated 'fixed' dunes and dune slacks. The methods of calculation of recharge and resulting recharge figures, as a percentage of MAP, are summarised in ***Table 5.11.2***.

Table 5.11.2
Recharge Related to MAP

Source (Reference)	Area	Method	% of MAP
GRA-II data-set (Department of Water Affairs and Forestry, 2006)	G21B	CMB[3]	15
	G21B - H Eskom		15
Atlantis Area groundwater potential (Department of Water Affairs and Forestry, 1982)	G21B - C Silwerstroom	Water Balance[4] (1978-1982)	25
Atlantis Area groundwater potential (Council for Scientific and Industrial Research, 1992)	G21B - Vegetated areas	Hydrograph Method[5]	23
	G21B - Non-vegetated dunes Witzand area	CMB	42
	G21B - vegetated Witzand area	CMB	25
Atlantis GMP Witzand Wellfield (Council for Scientific and Industrial Research, 1990)	G21B - Witzand area	Water Balance (1987-1989)	22
Atlantis Aquifer flow model (Council for Scientific and Industrial Research, 2017)	Atlantis Aquifer G21B	Literature review and model calibration	2-15
GMP = Groundwater Management Programme MAP = Mean Annual Precipitation; GRA-II = Groundwater Resource Assessment Phase II			

The GRA-II data-set provides an 'average' rainfall-recharge factor for the

[3] The chloride method is based on the fact that precipitation contains chloride from sea salt aerosol. During evaporation the concentration increases, and the increase is a measure of the evaporation. Together with rainfall data, and under the assumption of negligible runoff, recharge can be computed.

[4] The water balance method involves identifying all the inflow and outflow components of an aquifer and quantifying each one individually using field and long-term records.

[5] The hydrograph method means that if the storage coefficient of an aquifer is known, the spatially interpolated water table rise can be converted into a volume of water, which is equivalent to the recharge.

G21B quaternary catchment of 15 per cent using the Chloride Mass Balance (CMB) approach (***Drawing 5.11.4***) (Department of Water Affairs and Forestry, 2006). The variation in recharge values estimated from three different CMB assessments can be explained by them representing three different scenarios/physiographic settings, viz, unvegetated areas, vegetated areas and the whole study area.

Due to the unconfined nature of the upper sediments, rainfall recharge takes place over the entire area. Following a review of the recharge estimates in ***Table 5.11.2***, 25 per cent of MAP is considered to be representative for the Duynefontyn study area, at least on the unvegetated dune areas, possibly reducing to 15 per cent elsewhere. These values were tested for sensitivity in the numerical modelling described in ***Subsection 5.11.8***. Most of this recharge takes place during the wettest winter months, generally between May and August inclusive.

Direct recharge to the Malmesbury Aquifer is postulated to take place on areas of higher-lying ground inland from the site where these rocks are exposed at surface. Indirect recharge takes place by leakage from the Sandveld Aquifer depending on the head differential between the two aquifers (***Table 5.11.3***). Note: Head difference between the two aquifers increases from the coast to inland coinciding with, and attributed to, an increase in the saturated thickness of the Sandveld Aquifer in this direction, and also the fact that the coastal strip is a discharge area for both aquifers.

Table 5.11.3
Comparison of Groundwater Level Elevations in the Sandveld and Malmesbury Aquifers from the Coast to the Northern Boundary of the Enveloping Footprint

Distance from Coast	Coordinates (m)		Groundwater Level Elevation (m amsl)		
(m)	X	Y	Malmesbury Aquifer	Sandveld Aquifer	Difference (m)
0	-52 785.372	-3 727 210.099	9.631	9.916	0.285
38	-52 747.458	-3 727 139.975	10.398	10.918	0.520
76	-52 709.545	-3 727 069.850	11.230	12.086	0.856
114	-52 671.631	-3 726 999.726	12.064	12.947	0.883
152	-52 633.718	-3 726 929.601	12.916	13.817	0.901
190	-52 595.804	-3 726 859.476	13.747	14.644	0.897
227	-52 557.891	-3 726 789.352	14.294	15.503	1.210
265	-52 519.977	-3 726 719.227	14.677	16.346	1.670
303	-52 482.064	-3 726 649.103	14.906	17.257	2.351
341	-52 444.150	-3 726 578.978	15.075	18.118	3.043

Recharge Insights Using Tritium

The tritium (H-3) content of groundwater can provide a qualitative indication of recharge. Tritium concentrations are given as tritium units (TU), where one TU corresponds to one H-3 atom to 10^{18} hydrogen atoms, and is the standard unit used for discussion on groundwater recharge.

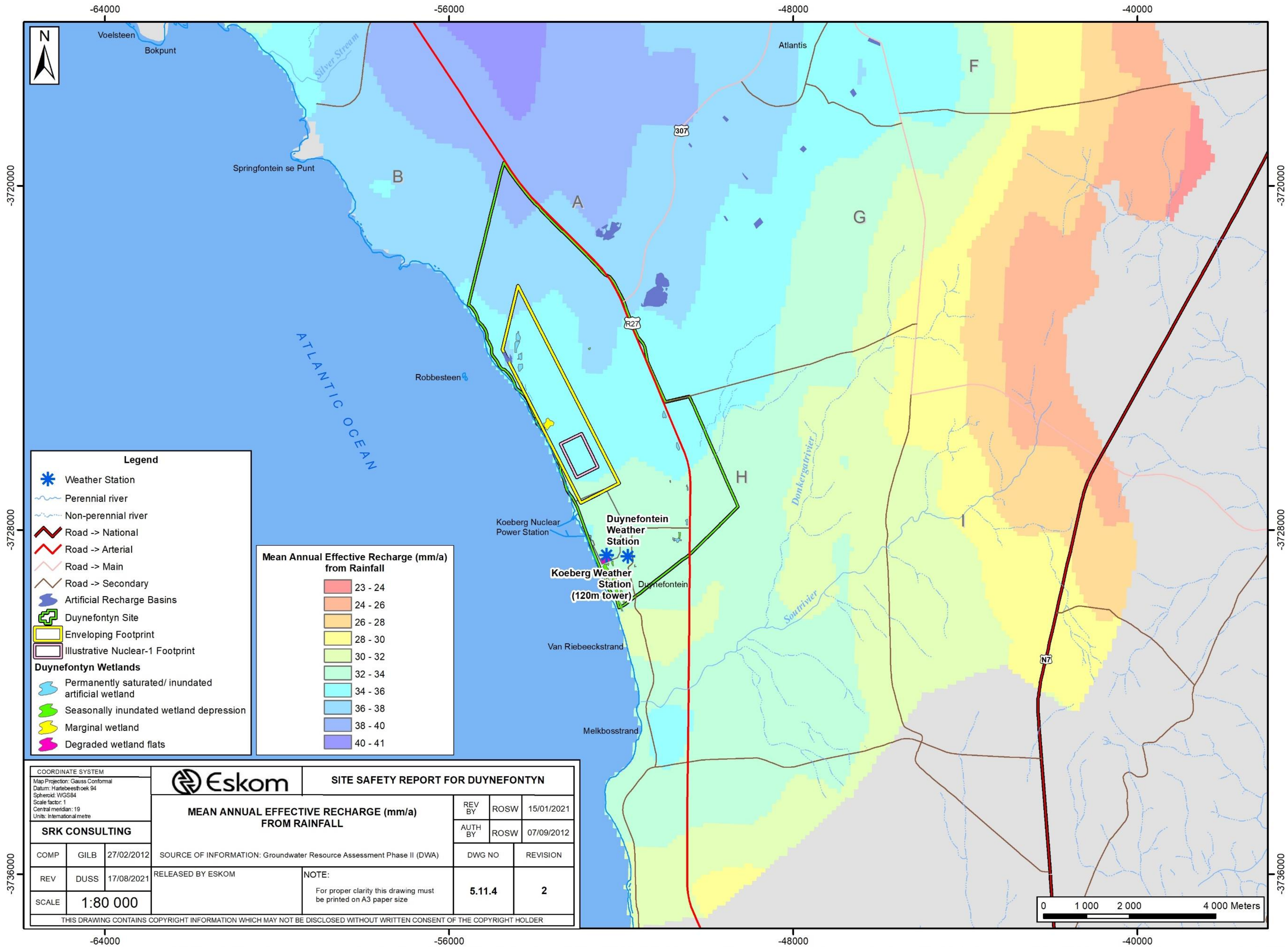
There are two main sources of H-3 in groundwater. It is naturally produced at low levels in the upper part of the atmosphere (about 10 to 20 km above the earth's surface) when cosmic rays collide with air molecules (cosmogenic processes). Tritium was also extensively produced from the atmospheric testing of hydrogen (atomic) bombs that began at the end of 1952 (nuclear fallout-produced), with the release of H-3 peaking in 1963. Tritium has a half-life of 12.32 years and this radioactive isotope of hydrogen was present in rainwater in Pretoria at a maximum concentration of around 16 TU in 1970. Since then, levels have been declining worldwide and are found in trace amounts in groundwater throughout the world (United States Nuclear Regulatory Commission, 2006) and (Lindsey, et al., 2019).

Tritium in groundwater is not significantly affected by chemical processes. Its most important use is in distinguishing between water that entered an aquifer prior to 1952 (i.e. pre-nuclear explosion testing) and water that was in contact with the atmosphere post-1952. Pre-1952 groundwater contains H-3 that is not detectable by normal laboratory procedures while post-1952 groundwater would contain relatively high levels of H-3. Tritium concentrations in groundwater have been interpreted as follows (Mazor, 1991):

- groundwater with zero H-3 (in practice, <0.5 TU) has a pre-1952 age;
- groundwater with H-3 concentrations >10 TU has a post-1952 age;
- Groundwater with H-3 concentrations of 0.5 to 10 TU represents a mixture of pre-1952 and post-1952 groundwater.

Tritium content in groundwater was used in previous investigations to determine areas of recharge (Africon, 2000). An interpretation of these results shows that in the secondary, fractured Malmesbury Aquifer, the groundwater regime is less dynamic than in the primary aquifer, which supports the hypothesis that negligible or no direct rainfall recharge to the Malmesbury Aquifer occurs in the vicinity of the site. As the site is located very close to the coastline, in terms of the hydrological/groundwater cycle, the site is in a groundwater discharge zone. Groundwater at the site is thus near the end of its flow path.

The deeper aquifer is recharged further inland, possibly several kilometres east of the site in areas where the Malmesbury rocks outcrop. Significant H-3 concentrations (>1 TU) in the primary aquifer indicate a fairly dynamic system with groundwater in the aquifer being some 10 to 20 years old and possibly also indicating incorporation of airborne H-3 releases from the KNPS into the shallow groundwater.



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5.11.5.4 Groundwater Levels and Flow Direction

Groundwater Levels

Hydrographs of water level measurements (one per month) in boreholes in close proximity to the site dating back to 1985 show no indication of significantly declining water levels. It is, therefore, apparent that groundwater levels have not been negatively impacted by abstraction from the Witzand or Aquarius wellfields (***Figure 5.11.1)***. Seasonal trends are evident, as are short duration influences caused by pumping.

The Aquarius and Witzand wellfields are the closest groundwater abstraction areas to the site. At these wellfields, the water table ranges between 3 and 12 m bgl, at rest. Numerical modelling of the effect of abstraction from the Silwerstroom and Witzand wellfields (2.2 and 3.5 million m^3/a, respectively, in 1995) and from the Aquarius Wellfield (480 000 m^3/a maximum, but it has never been pumped anywhere near this level) on groundwater levels showed that there would be no significant impacts at either the KNPS or at the new nuclear installation footprint area (Council for Scientific and Industrial Research, 1995). This has been borne-out by SRK's 2008 to 2020 monitoring results (SRK Consulting (South Africa) Pty Ltd, 2020). Abstraction from all three wellfields has been reduced over time due to operational constraints such as clogging of well screens (Atlantis wellfields) and poor water quality (Aquarius Wellfield). Abstraction from the Atlantis wellfields in 2010 was about 5 million m^3/a and the CCT is looking to obtain an additional 11 to 14 Mℓ/day (*c.*4 to 5 million m^3/a) from the Witzand Wellfield as part of its water supply augmentation project (pers. comm. C Lasher-Scheepers, 2020).

Measurement of groundwater levels over the site indicates that they fluctuate between 1.0 and 4.5 m bgl. Seasonal (winter recharge) and tidal impacts are the dominant factors influencing local groundwater level fluctuations (Council for Scientific and Industrial Research, 2000). Groundwater levels measured in the deeper boreholes (i.e. secondary aquifer) and those measured in the shallow boreholes (i.e. primary aquifer) differ by <0.5 m (see ***Figure 5.1.1***).

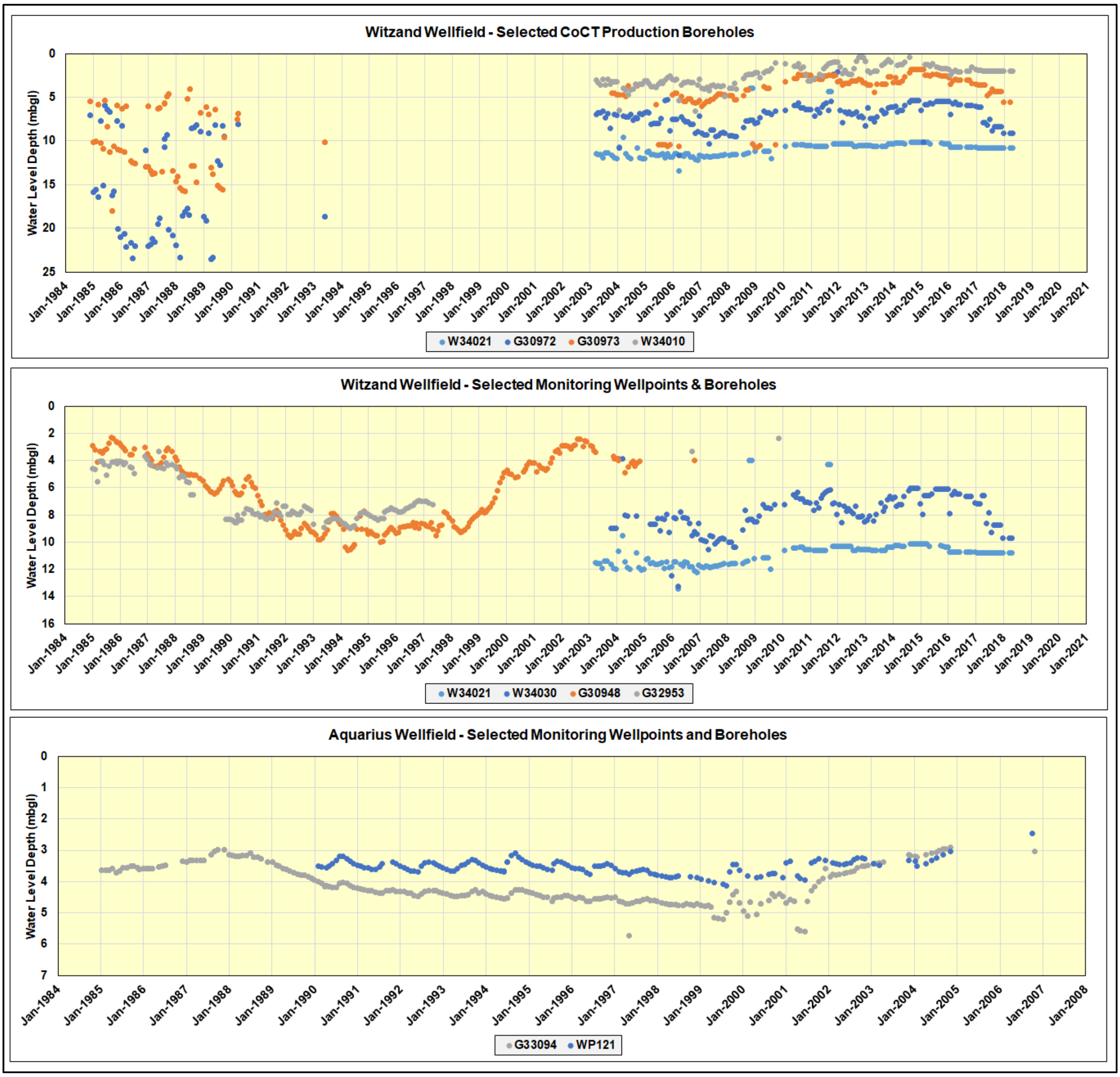


Figure 5.11.1
Borehole Groundwater Levels at the Witzand and Aquarius Wellfields

Based on previous observations, groundwater levels west of the KNPS fluctuated by between 0.55 and 0.70 m during construction (Eskom, 2006).

The water level fluctuation record from the PBMR monitoring boreholes is shown in ***Figure 5.11.2*** (Sandveld Aquifer) and ***Figure 5.11.3*** (Malmesbury Aquifer) below (SRK Consulting, 2010), along with rainfall records from the Koeberg weather station. PBMR-1 and PBMR-5 (***Figure 5.11.3***) tap the Malmesbury Aquifer while the rest of the boreholes (***Figure 5.11.2***) tap the Sandveld Aquifer. This Figure shows fairly minor seasonal fluctuations of mostly <1 m in response to the wet winter (June to September) and drier summer periods.

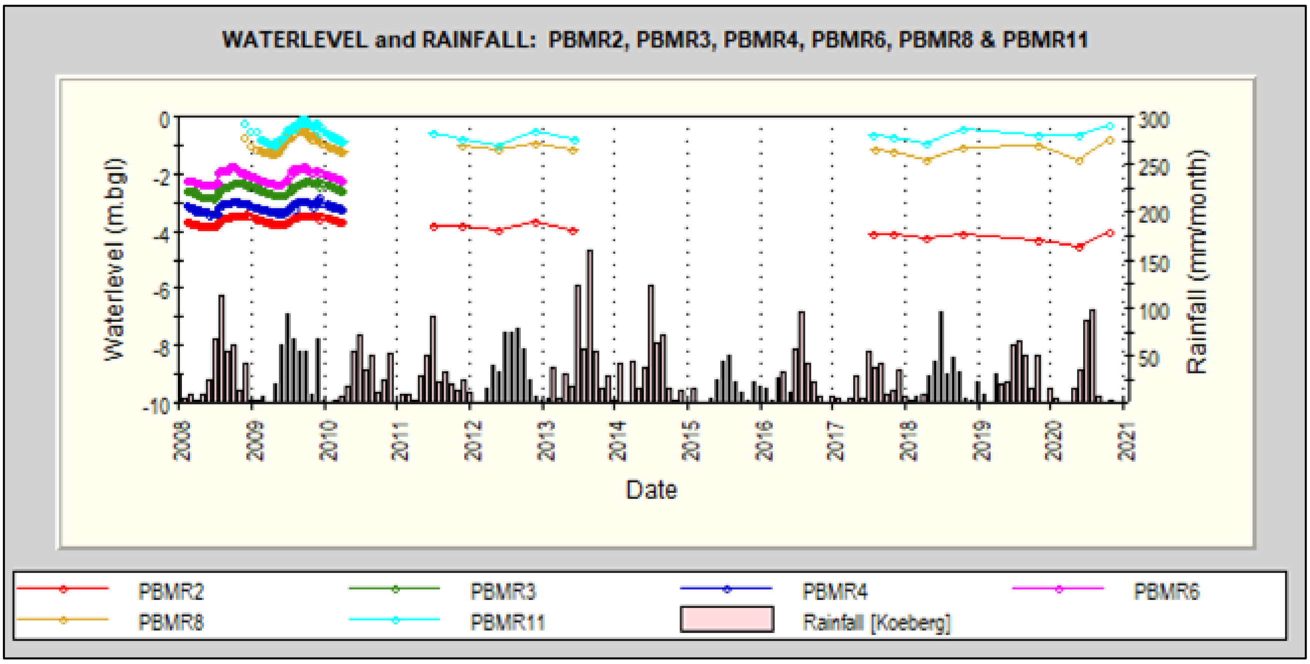


Figure 5.11.2
Groundwater Levels vs Rainfall at the Proposed PBMR DPP Site Sandveld Aquifer Monitoring Boreholes

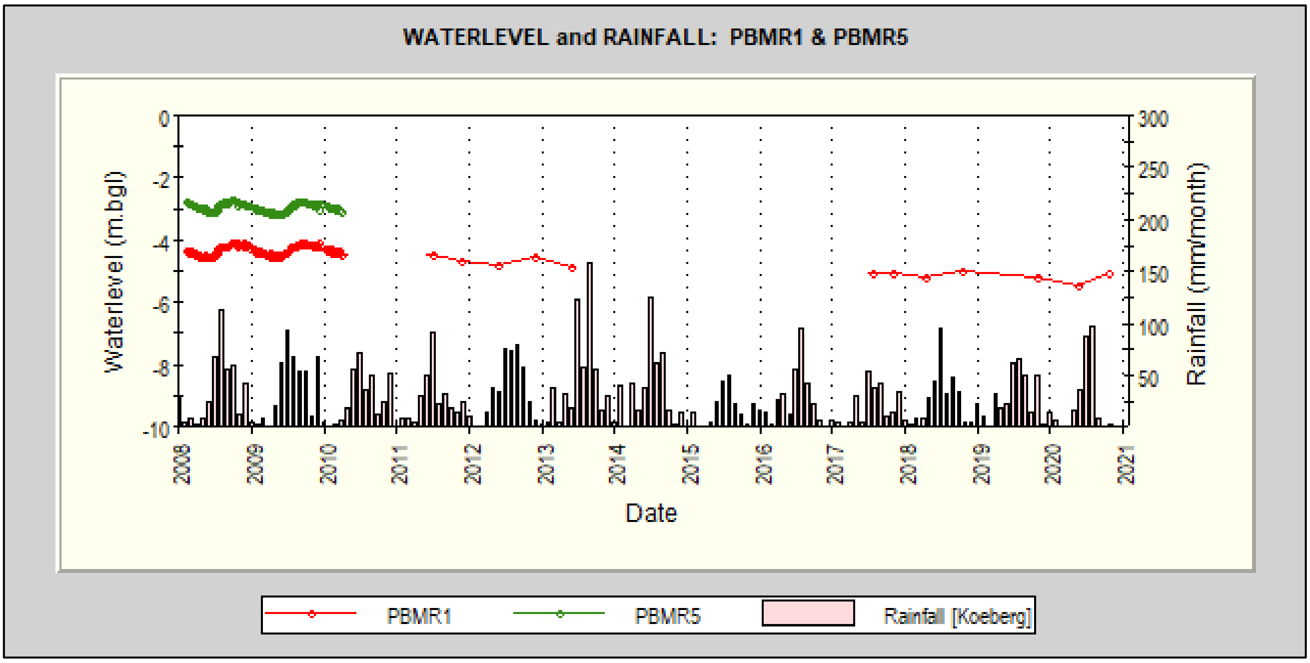


Figure 5.11.3
Groundwater Levels vs Rainfall at the Proposed PBMR DPP Site Malmesbury Aquifer Monitoring Boreholes

Direction of Groundwater Flow

A regional groundwater level contour map (***Drawing 5.11.5***) was compiled using data collected from previous monitoring carried out by the Council for Scientific and Industrial Research and that collected during a hydrocensus conducted during August and September 2004 (Parsons and Associates, 2006). From these hydrocensus data, it was interpreted that groundwater flows in a generally southwesterly direction towards the coast.

According to the results of previous numerical modelling, even at a high abstraction rate of 32 ℓ/s at the Aquarius Wellfield, i.e. twice the recommended sustainable rate of 16 ℓ/s, the resulting maximum zone of drawdown will not reach the new nuclear installation(s) footprint or the KNPS (Council for Scientific and Industrial Research, 2000). Drawdown at the footprint/KNPS due to upstream pumping would in any case not give rise to safety issues with respect to the nuclear installation(s).

5.11.5.5 Groundwater Quality

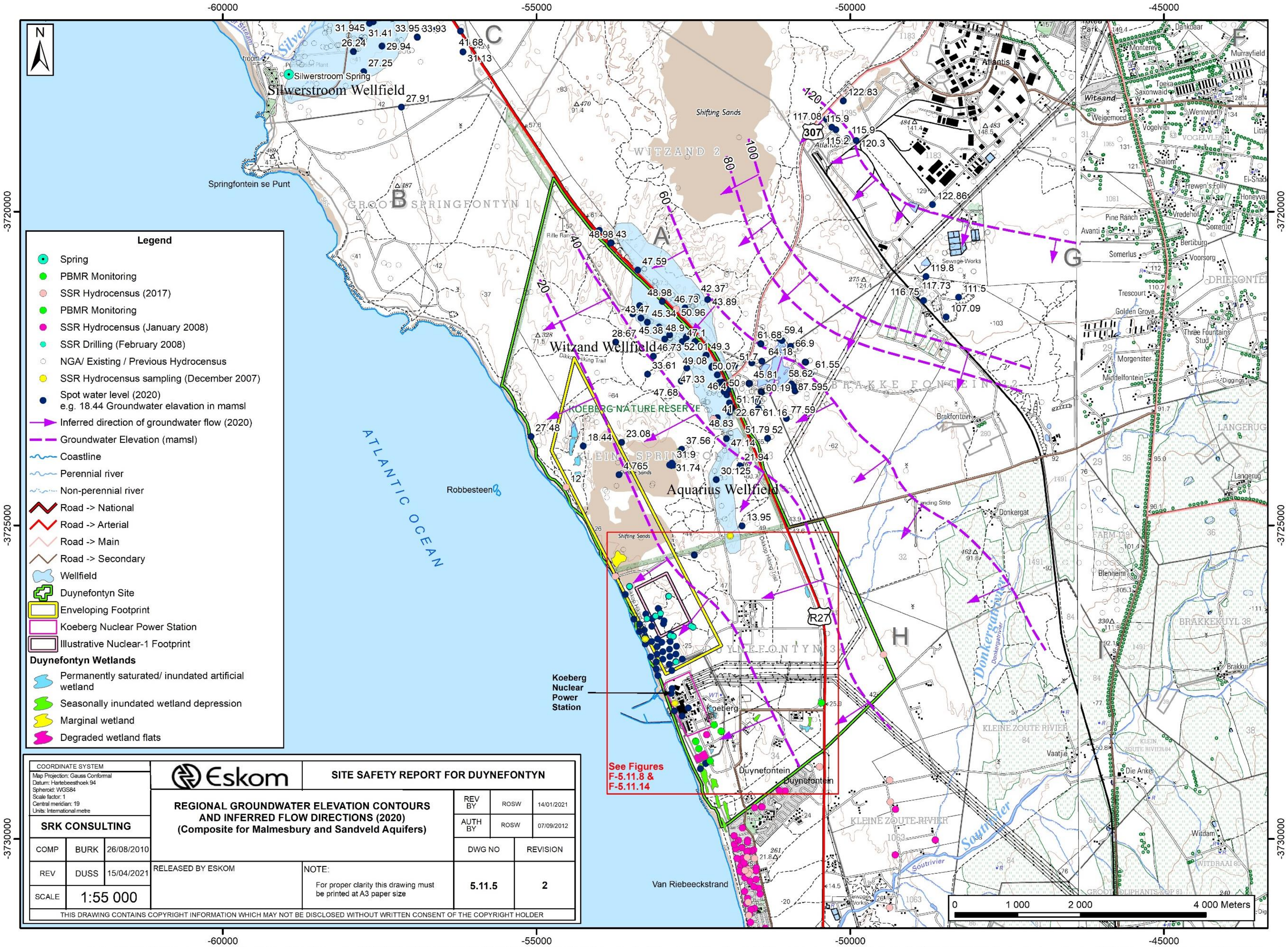
Regional groundwater quality in terms of electrical conductivity (EC) is shown in ***Drawing 5.11.6***, as taken from the DWAF hydrogeological map (Department of Water Affairs and Forestry, 2000). These data indicate that

EC at the site and towards the south and east is in the range of 300 to 1 000 mS/m. In the northern part, north and northeast of the site, the EC is in the range of 70 to 300 mS/m. A thin band of low EC (<70 mS/m) extends from Robbesteen inland towards Atlantis. The area of unvegetated dunes with postulated high recharge lies astride this low EC zone and the enhanced recharge here may be the cause of the lower EC groundwater here.

Regional groundwater quality of the Atlantis Aquifer has been previously investigated in detail (Department of Water Affairs and Forestry, 1982). The groundwater of this aquifer was classified as a Class I type (EC <70 mS/m) (Council for Scientific and Industrial Research, 1990). The groundwater is generally of a sodium chloride (NaCl) type, but younger groundwater in the vicinity of the site tends towards a calcium bicarbonate [$Ca(HCO_3)_2$] character. Interpretation of more recent groundwater quality data collected over the site confirms that groundwater quality in the vicinity of the site has a NaCl character, which is typical of groundwater in coastal environments (Africon, 2000), (SRK Consulting, 2010), and (SRK Consulting, 2020). Based on site monitoring data and previous investigations, groundwater at the site also tends to show a magnesium sulfate ($MgSO_4$) and magnesium chloride ($MgCl_2$) character.

Due to the large amount of groundwater chemistry data available for the Aquarius, Witzand and Silwerstroom wellfields and from work done at the site (PBMR and KNPS), only four boreholes were sampled for chemical, radiological and isotope analysis during the January 2008 hydrocensus. The chemical data are shown in ***Table 5.11.4*** and details of the boreholes sampled are given in ***Table 5.11.13***. Note that ***Table 5.11.4*** indicates groundwater chemistry from four Sandveld Aquifer boreholes sampled as a once-off during the 2007 hydrocensus, whilst ***Table 5.11.17***Table 5.11.13 indicates groundwater chemistry of samples collected from the Sandveld Aquifer monitoring boreholes from 2008 to 2019. Comparisons of the groundwater chemistry of the various samples are indicated as Piper Diagrams in ***Figure 5.11.5*** and ***Figure 5.11.15***.

Based on previously documented field measurements, EC levels at the site range between 85 and 215 mS/m. At the Aquarius Wellfield EC ranged from 135 to 200 mS/m at the time of installation (Groundwater Consulting Services, 1996). More recent yield testing of these boreholes (Advisian, 2018) shows a range of EC of 100 to 291 mS/m, with EC increasing towards the coast.



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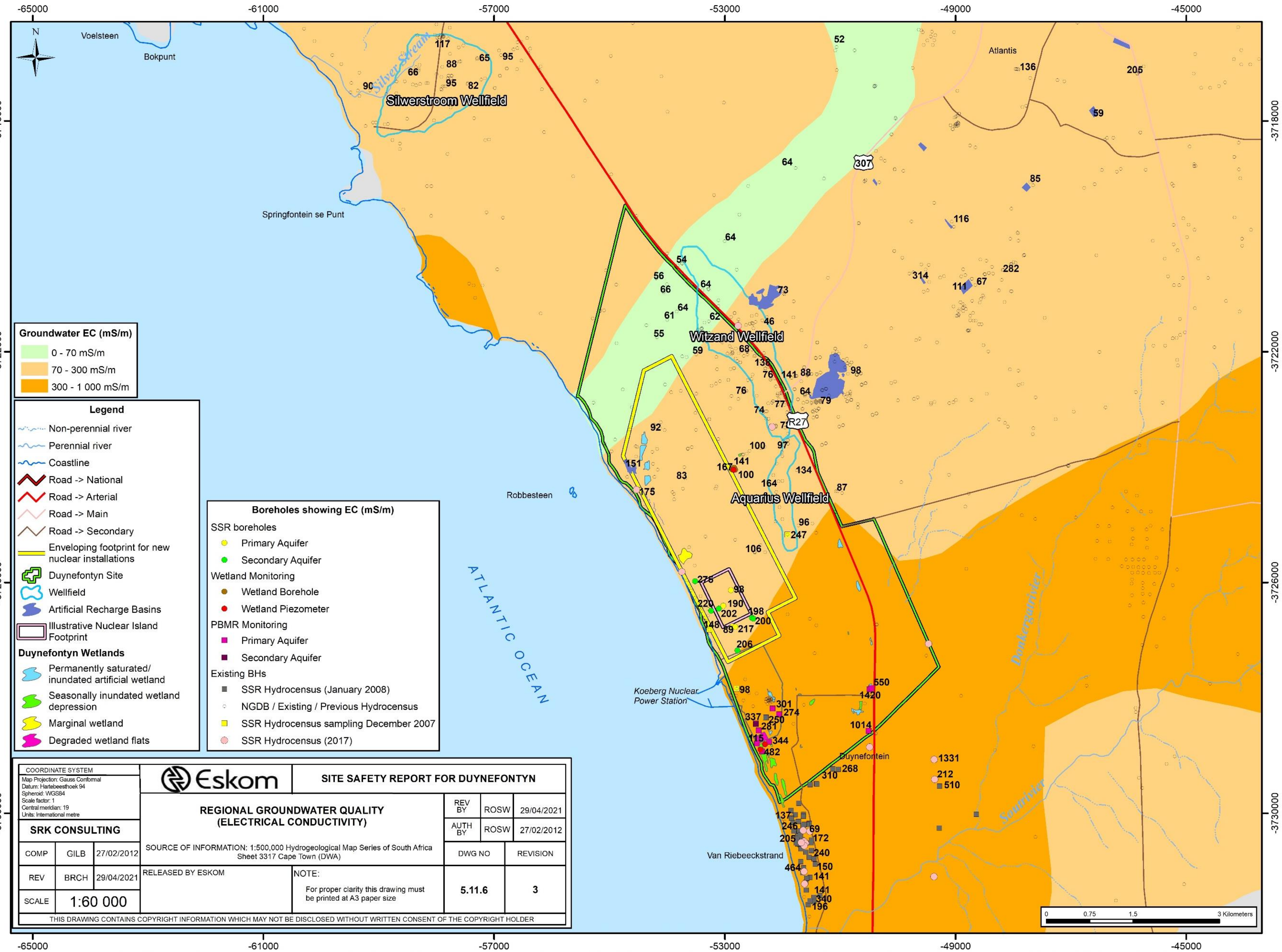

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Groundwater quality monitoring data available for the Witzand Wellfield indicate that EC varies between 50 and 250 mS/m. Some 18 wellpoints were previously installed along the coastline (along the western boundary of the site), and EC levels at these wellpoints ranged from 65 to 150 mS/m (Council for Scientific and Industrial Research, 1993). Groundwater samples from the Sandveld Aquifer at three boreholes and one wellpoint (E08, GCS1, PBMR-BH and TW2) were collected in close proximity to the site during the 2008 hydrocensus. The EC levels of these samples range between 100 and 250 mS/m. Salinity variations in groundwater from production boreholes in the Aquarius, Silwerstroom and Witzand wellfields are shown in ***Figure*** 5.11.4.

Table 5.11.4
Chemical Analyses: December 2007 Sandveld Aquifer Hydrocensus Samples

Determinand	Units	Boreholes			
		E08	GCS01	PBMR-BH	TW2
Calcium	mg/ℓ	97.4	109.4	242.8	71.8
Magnesium	mg/ℓ	34.4	45.0	56.1	8.6
Sodium	mg/ℓ	156.7	423	288.6	95.9
Potassium	mg/ℓ	6.5	3.3	18.9	44.4
Alkalinity as $CaCO_3$	mg/ℓ	260	194	327	221
Chloride	mg/ℓ	300	211	155	155
Sulfate	mg/ℓ	44.5	95.6	227.8	42.3
Nitrate as N	mg/ℓ	0.47	<0.025	14.3	3.24
Fluoride	mg/ℓ	0.25	0.15	0.32	0.13
Total Iron	mg/ℓ	1.7	1.52	0.10	0.03
Total Manganese	mg/ℓ	0.63	0.06	<0.05	<0.05
Ammonia as N	mg/ℓ	<0.025	0.068	<0.025	<0.025
Phosphorus (Ortho-P) as PO_4	mg/ℓ	0.153	0.156	0.171	0.845
pH	pH units	7.7	7.3	7.4	8.5
EC	mS/m	148	247	250	98

The chemical character of the groundwater is a direct result of the proximity of these aquifers to the ocean, i.e. at the end of the flow path and influence of frontal rainfall recharge and sea-spray/aerosols (***Drawing 5.11.6***).

It was concluded that groundwater derived from the Sandveld Aquifer underlying the site and that from the Malmesbury Aquifer are of a similar quality (Council for Scientific and Industrial Research, 2001). This similarity supports the hypothesis that the two aquifer systems are to a degree hydraulically connected and that the Malmesbury Aquifer is a semi-confined system. Although EC levels and Na and Cl concentrations are similar, the average iron (Fe) concentration in the secondary aquifer is greater at 3.7 mg/ℓ (as compared to about 0.3 mg/ℓ in groundwater of the Sandveld Aquifer) (Council for Scientific and Industrial Research, 2001). This might be due to the conditions in the Malmesbury Aquifer being more reducing thus increasing the mobility of the ferric ion. Note that more up-to-date monitoring data are described under the site-specific aquifer characteristics in the following subsections and further inferences are drawn on water quality of the two aquifers.

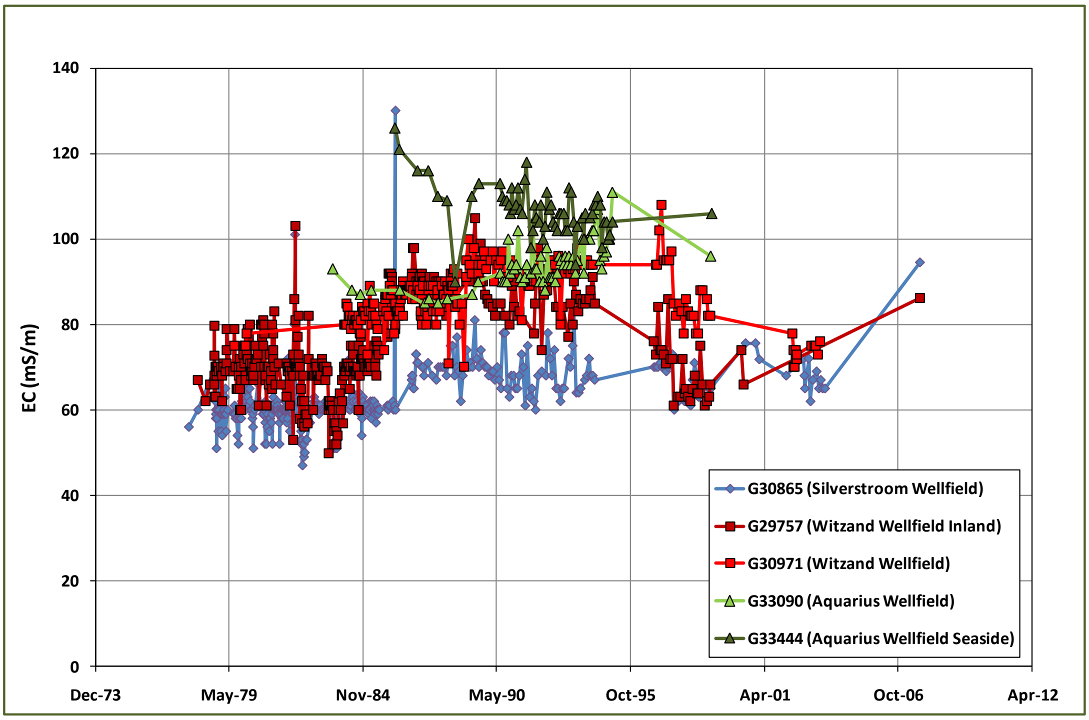


Figure 5.11.4
Temporal EC Variation of the Regional Sandveld Aquifer Wellfields

Trilinear Piper plots of water samples taken during the December 2007 hydrocensus is shown in ***Figure 5.11.5***. Representative analyses of previous samples from the NGA and Witzand, Aquarius and Silwerstroom wellfields are also represented in the Piper plot. Piper plots of more recent samples taken at the Aquarius Wellfield in November 2017 are shown in ***Figure 5.11.6*** and at the KNPS monitoring boreholes (2008 to 2019) are shown in ***Figure 5.11.7***. All these previously analysed groundwater samples have a dominant Na-Cl-SO_4 character, which is typical for coastal environments.

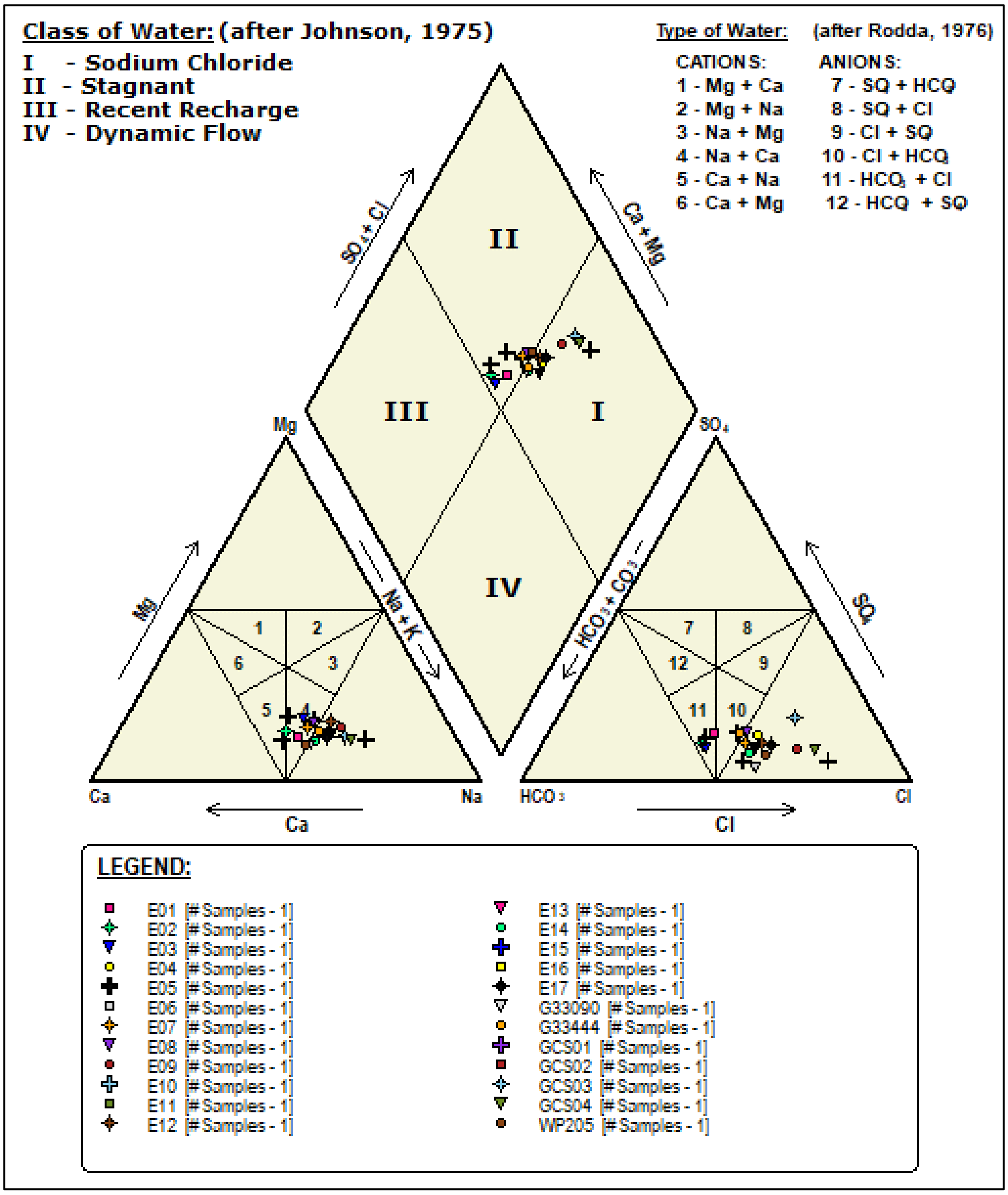


Figure 5.11.5
Piper Diagram: Sandveld Aquifer Regional Wellfield and December 2007 Hydrocensus Data

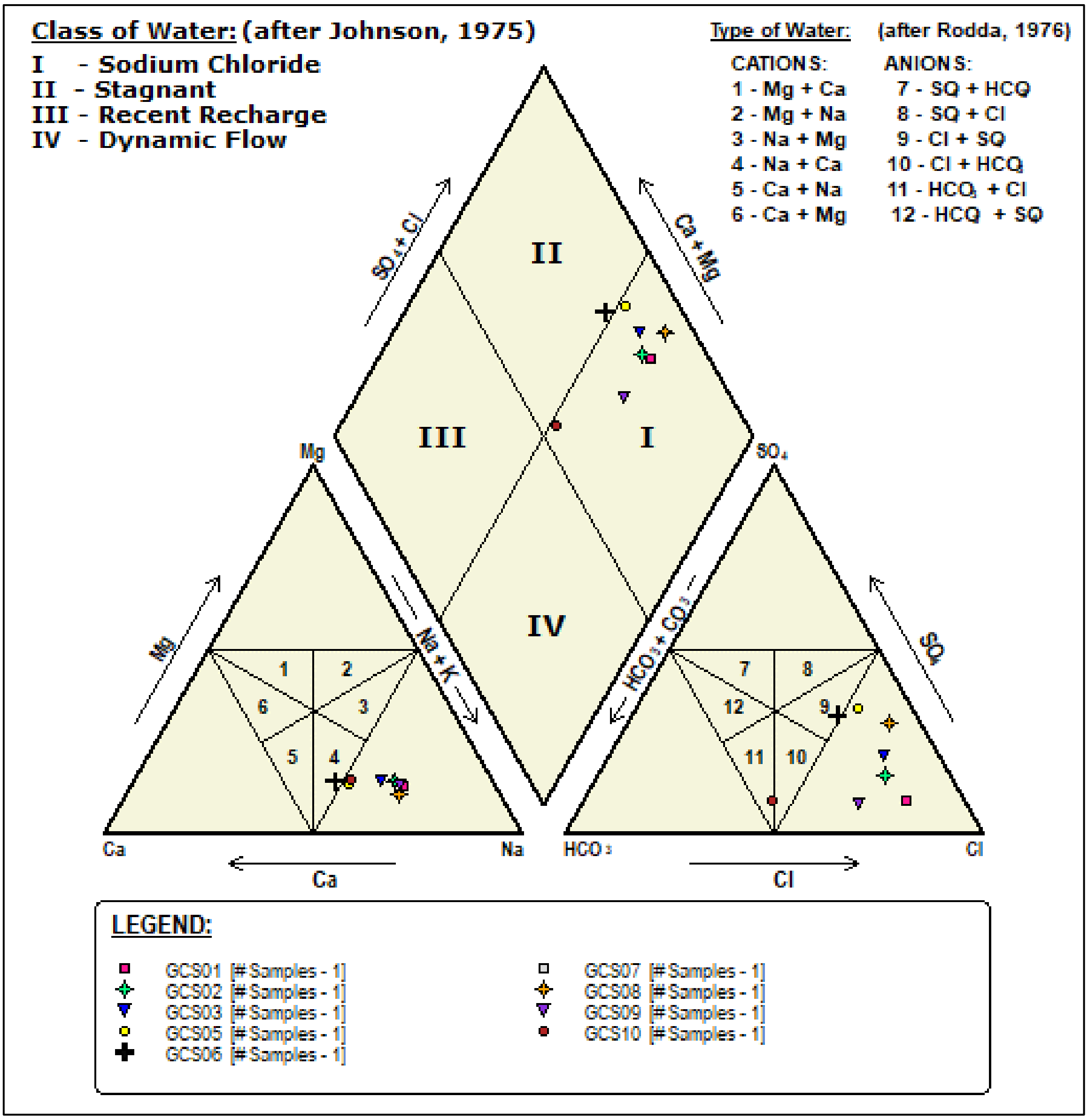


Figure 5.11.6
Piper Diagram: Aquarius Wellfield Chemistry November 2017 (Sandveld Aquifer)

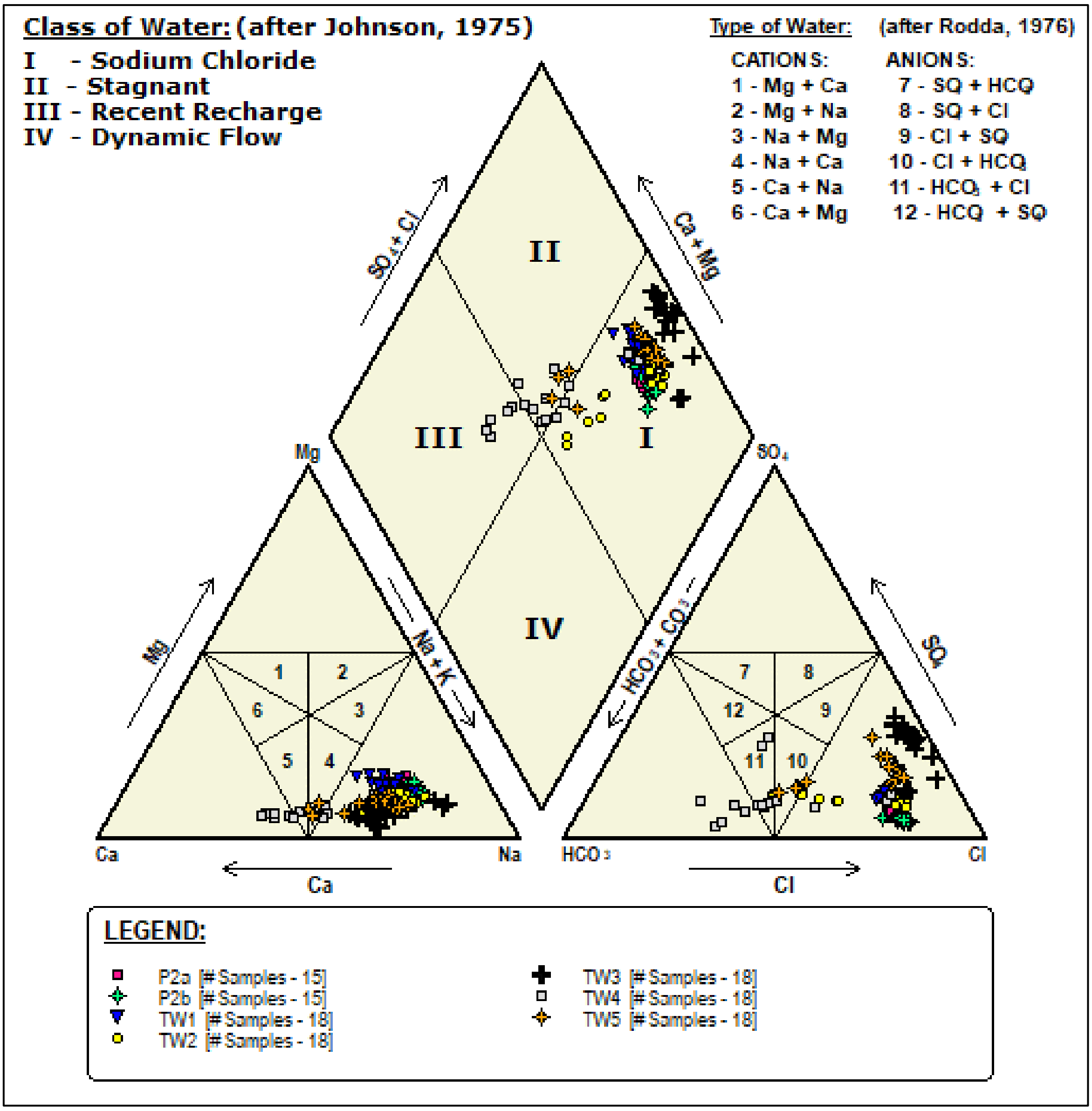


Figure 5.11.7
Piper Diagram: KNPS Monitoring Borehole Chemistry 2008 to 2019

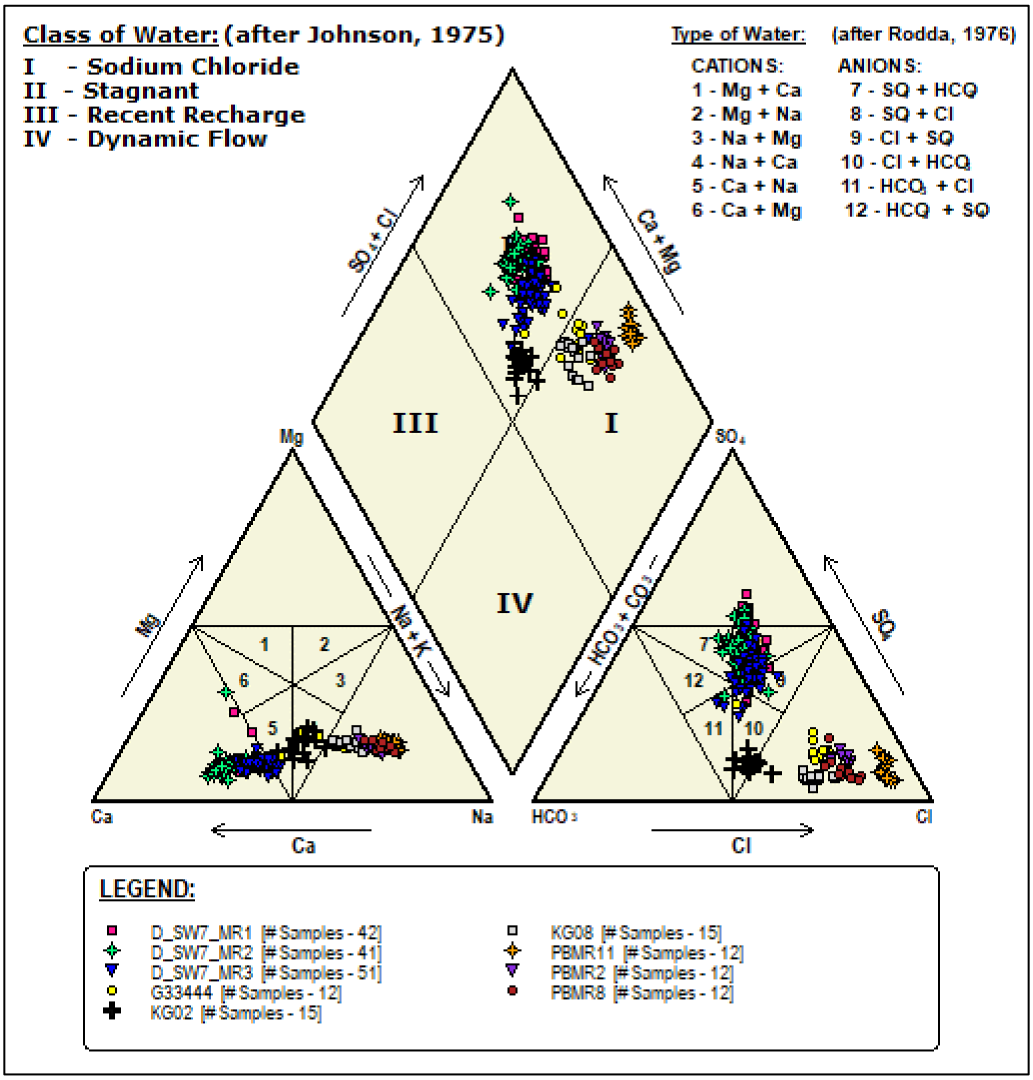


Figure 5.11.8
Piper Diagram: Sandveld Aquifer SSR Monitoring Borehole Chemistry 2008 to 2020

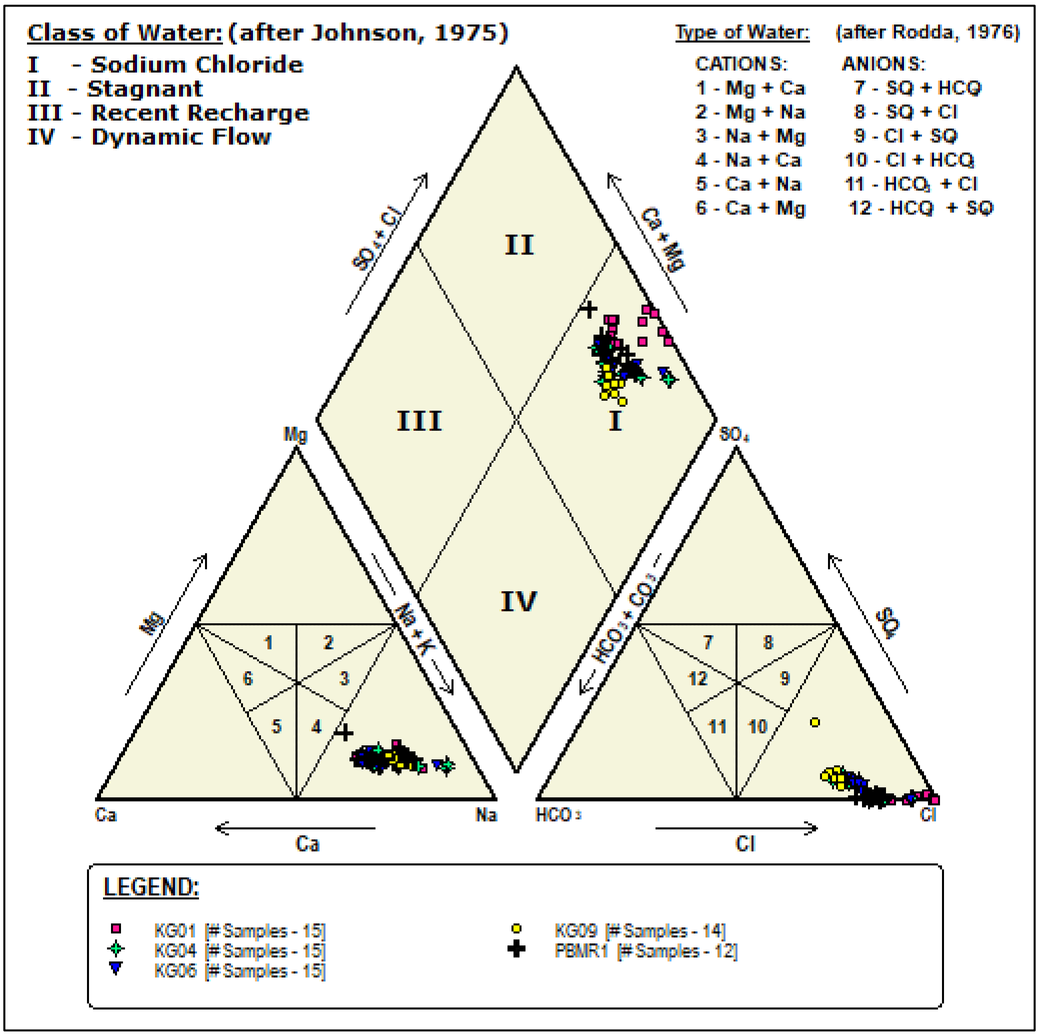


Figure 5.11.9
Piper Diagram: Malmesbury Aquifer SSR Monitoring Borehole Chemistry 2008 to 2020

Chemical characteristics of groundwater from the different aquifers in the area, based on the latest information, can thus be summarised as follows:

- Malmesbury Aquifer – NaCl type and acidic to neutral pH;
- Sandveld Aquifer - mixed NaCl, $Ca(HCO_3)_2$, $MgSO_4$ type and neutral to alkaline pH.
- Piper diagram plots indicate some mixing of Malmesbury Aquifer groundwater with the Sandveld Aquifer, especially at the deeper SSR boreholes KG02 and KG08, at G33444, PBMR2, PBMR8 and PBMR11. The three shallow (<15 mbgl) D-SW7-MR wetland monitoring boreholes indicate a different, more stagnant, $MgSO_4$ type groundwater.
- Some of the groundwater is fit for human use and this is described in detail in ***Subsection 5.11.5.7***.

Radionuclide analyses (standard suite for assessment of domestic water radiological quality) of water samples taken during the December 2007 and July 2017 hydrocensuses were also conducted by the Nuclear Energy Corporation of South Africa (Necsa). The results of these analyses are presented in ***Table 5.11.5***, ***Table 5.11.6*** and ***Table 5.11.7***.

Table 5.11.5
Radionuclide Analyses: December 2007 Hydrocensus Samples

Sample ID	U-238			Th-232			Ra-226			Ra-223		
	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
E08	22.1	4.4	5.7	15.1	2.4	1.0	42.8	4.4	1.2	3.8	4.8	8.6
GCS01	45.6	8.5	4.3	7.22	1.66	1.0	32.8	4.0	1.3	2.3	3.9	4.5
PBMR-BH	69.0	8.2	7.0	13.8	2.9	4.1	17.2	3.2	5.4	7.98	3.58	3.6
TW2	24.2	4.9	2.7	1.04	0.6	0.94	7.94	1.98	1.3	3.8	2.6	5.8
mBq/ℓ = milli-Becquerel per litre												
MDA = minimum detectable activity concentration (@ 95% confidence level)												
1θ = reported uncertainty from counting statistics												

Table 5.11.6
Radionuclide Analyses: July 2017 Hydrocensus Samples

Sample ID	Ra-226			Ra-224			Ra-223		
	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
11 DUIK	26.60	3.70	1.40	5.26	2.35	2.90	12.00	3.70	1.80

Sample ID	Ra-226			Ra-224			Ra-223		
	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
23 HERN	74.30	5.90	1.30	0.98	0.98	2.70	-4.00	4.20	1.70
22 HERN	116.00	7.00	1.00	1.60	1.10	2.20	-8.30	4.60	1.40
2 HERN	111.00	7.00	1.30	2.00	1.40	2.70	0.25	5.40	1.80
80 CHAR	105.00	25.00	16.00	< MDA		55.00	16.00	14.00	17.00
1063/18	24.00	3.20	1.20	< MDA		2.50	-2.30	2.20	1.60
1063/24A	13.70	2.90	1.70	< MDA		3.50	2.00	2.50	2.30
8 KORH	19.20	3.20	7.10	3.40	3.00	10.00	-0.54	1.50	4.50
MV 1	153.00	7.00	4.30	8.33	3.29	7.60	-0.32	3.10	3.50
OKL 1	862.00	17.00	4.10	53.30	7.60	9.30	2.40	7.10	2.80
WP 212	4.11	1.45	3.70	18.40	5.20	12.00	0.71	0.75	1.30
EAST 1	63.80	4.80	0.96	2.97	1.48	2.00	-6.00	3.20	1.30
G33464	36.50	4.30	1.40	4.19	2.10	2.80	-1.00	3.10	1.80
WP171A	60.40	4.70	1.00	0.77	0.77	2.10	-0.68	3.50	1.30
W34019	3.20	1.50	4.30	6.70	3.10	9.00	0.93	1.20	2.30
mBq/ℓ = milli-Becquerel per litre									
MDA = minimum detectable activity concentration (@ 95% confidence level)									
1θ = reported uncertainty from counting statistics									

Table 5.11.7
Gross Alpha & Beta Analyses: July 2017 Hydrocensus Samples

Sample ID	Unit	Gross α			Gross β		
		mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
11 DUIK	mBq/ℓ	140	170	560	1040	130	380
23 HERN	mBq/ℓ	40	110	370	531	116	360
22 HERN	mBq/ℓ	-78	170	590	627	122	380
2 HERN	mBq/ℓ	-26	150	510	423	117	370
80 CHAR	mBq/ℓ	-210	140	510	473	118	370
1063/18	mBq/ℓ	-110	110	390	210	110	360
1063/24A	mBq/ℓ	-120	110	400	653	118	360
8 KORH	mBq/ℓ	-210	140	500	636	120	370
MV 1	mBq/ℓ	-530	420	1500	570	190	620
OKL 1	mBq/ℓ	130	530	1800	1930	240	640
WP 212	mBq/ℓ	-160	79	290	200	110	350
EAST 1	mBq/ℓ	-340	170	620	250	120	380
G33464	mBq/ℓ	-120	96	340	260	110	360
WP171A	mBq/ℓ	-130	100	370	140	110	360
W34019	mBq/ℓ	-220	91	330	97	110	360
mBq/ℓ = milli-Becquerel per litre							
MDA = minimum detectable activity concentration (@ 95% confidence level)							

1θ = reported uncertainty from counting statistics

5.11.5.6 Stable Isotopes and Tritium

Isotopes of hydrogen and oxygen are ideal geochemical tracers of groundwater since their concentrations are not subject to change due to interaction with the aquifer. Once underground and removed from zones of evaporation, the isotope ratios are conserved/stable and are only affected by mixing with other media. Groundwater in the saturated zone thus has an isotopic composition corresponding to the mean isotopic composition of infiltration in the area. This may differ slightly from the mean isotopic precipitation due to the fact that not all precipitation throughout the year infiltrates in the same proportion (Mazor, 1991).

Site groundwater samples were previously analysed for the stable isotopes deuterium (H-2) and oxygen-18 (O-18) (Africon, 2000). These analyses were undertaken to determine the origin and age of groundwater at the site and to provide an estimate of the degree of mixing of groundwater in the primary and secondary aquifers and to indicate the rate of groundwater flow. Based on the results, O-18 concentrations in the dune areas (the higher lying areas) represent ‘young’, recently recharged groundwater, whereas along the lower lying areas where the depth to groundwater is shallow, the O-18 concentration is related to evaporation processes, and the values represent mixed groundwater (Africon, 2000).

The four hydrocensus boreholes sampled during December 2007 were analysed for H-3, H-2 and O-18. These results assist in the assessment of the origin and recharge of groundwater. The results of these analyses are presented in ***Table 5.11.8***. Note that the geohydrology is addressed first from a regional and historic perspective and thereafter from a site-specific perspective, which is based on site investigations and monitoring.

Table 5.11.8
Stable Isotope and Tritium Analyses: December 2007 Hydrocensus Samples

Sample ID	Aquifer	H-2 (‰)*	O-18 (‰)	Tritium (H-3) (TU)	
E08	Sandveld	-19.0	-3.78	1.9	±0.3
GCS01	Sandveld	-21.3	-4.25	0.2	±0.3
PBMR-BH	Sandveld	-18.4	-3.81	4.2	±0.4
TW2	Sandveld	-9.5	-2.18	3.6	±0.4

* ‰ – per mil is the ratio of stable isotope mass D/H or O-18/O-16 atomic weight and mol fractions per thousand. The ‘minus’ sign indicates that the sample is depleted in that isotope

Table 5.11.9
Tritium Analyses: July 2017 Hydrocensus Samples

Sample ID	Aquifer	Date Sampled	Tritium (H-3) (TU)	
11 DUIK	Sandveld	28/07/2017	2.2	±0.3
23 HERN	Sandveld	27/07/2017	1.4	±0.3
22 HERN	Sandveld	27/07/2017	1.2	±0.3
02 HERN	Sandveld	27/07/2017	1.3	±0.3
80 CHAR	Sandveld	27/07/2017	2.0	±0.3
1063/18	Sandveld	28/07/2017	1.6	±0.3
1063/24A	Sandveld	28/07/2017	0.6	±0.2
8 KORH	Sandveld	28/07/2017	1.6	±0.3
MV1	Sandveld	04/08/2017	<0.2	±0.2
OKL1	Sandveld	04/08/2017	0.7	±0.2
WP212	Sandveld	04/08/2017	1.4	±0.3
EAST1	Sandveld	04/08/2017	0.3	±0.2
G33464	Sandveld	03/08/2017	0.9	±0.2
WP171A	Sandveld	03/08/2017	0.7	±0.2
W34019	Sandveld	03/08/2017	1.3	±0.3

Four exploration boreholes were drilled at the planned PBMR DPP site location (Africon, 2000). Tritium data from groundwater in these boreholes indicated that groundwater in the Malmesbury Aquifer is not recharged locally, which indicates differentiation in age and quality between the primary aquifer and the secondary aquifer. Future pumping and dewatering is likely to disturb this relationship.

Figure 5.11.10 presents a plot of H-2 vs. O-18 for data from previously analysed samples from KNPS and PBMR DPP locations (Council for Scientific and Industrial Research, 1993) and the hydrocensus samples relative to the Global Meteoric Water Line (GMWL[6]). The majority of the samples represent groundwater from the primary aquifer. Although this is a relatively old reference, the general trends indicated still remain valid.

[6] GMWL – H-2 and O-18 content of rain water from sampling sites around the world lie along a straight line known as the Global Meteoric Water Line.

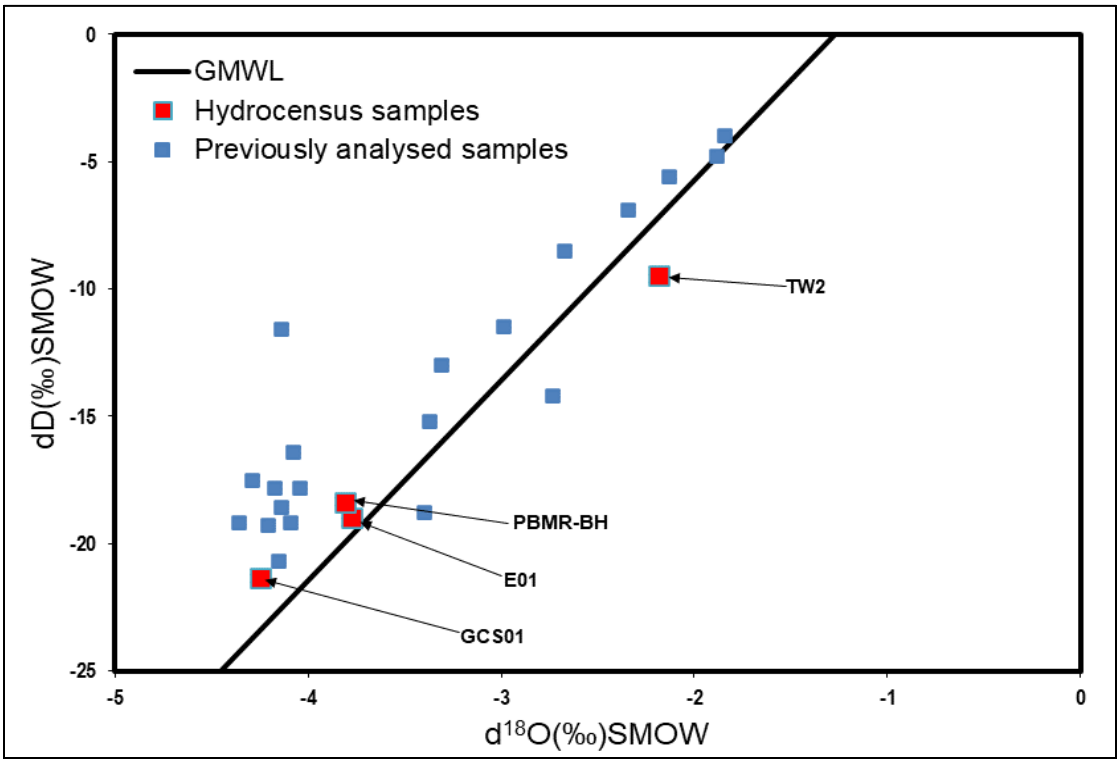


Figure 5.11.10
O-18 versus H-2 for Previously Analysed and Hydrocensus Samples[7]

The SSR hydrocensus samples have a strong correlation with the GMWL. The previously analysed samples from locations at the KNPS and proposed PBMR DPP site trend to a cluster just above the GMWL. Water with an isotopic composition falling on the GMWL is assumed to originate from the atmosphere and therefore has not been affected by 'artificial' isotopic processes (Craig, 1961). Deviations from the GMWL result from other isotopic processes such as evaporation from open water (e.g. wetlands and rivers) and exchange with rock minerals. The majority of the samples plot slightly above the GMWL, which is to be expected for a Mediterranean climate, i.e. enriched waters are found in warmer regions (Craig, 1961). The cluster trend above the GMWL indicates uniform and localised direct recharge. Borehole TW2 is located on the coastline, which may explain the slight enrichment of O-18.

Tritium Analysis

The H-3 content of groundwater can provide a qualitative indication of recharge. Shallow groundwater H-3 values reflect the local average precipitation values but are modified to some extent by selective recharge

[7] SMOW: Standard mean ocean water, an international reference standard used to determine the oxygen and hydrogen isotopic content of water.

and fractionation processes that may alter the H-3 values of the precipitation before the water reaches the saturated zone. These processes include evaporation of rain during infiltration, selective recharge (e.g., only from major storms), interception of rainwater by vegetation, exchange of infiltrating water with atmospheric vapor, and various post-depositional processes (e.g., evaporation during infiltration). Isotopic fractionation during evaporation is mainly a function of ambient humidity. During light rains, the H-3 concentration is representative of the moisture at lower levels, while during moderate or heavy rains the exchange at lower levels is insignificant. Re-evaporated water has nearly the same H-3 concentration as the original precipitation.

Groundwater from the Aquarius Wellfield (GCS1) has an H-3 concentration of 0.2 TU, while groundwater along the coast, along the western boundary of the site (sample E08) has a concentration of 1.9 TU. However, samples collected at the KNPS and planned PBMR DPP site show H-3 concentrations of 3.6 and 4.2 TU, respectively (samples PBMR-BH and TW2). These slightly elevated values could be attributed to emissions from the KNPS. Groundwater monitoring for KNPS has also picked up elevated H-3 levels periodically (Advisian, 2016). However, surface water monitoring in 2019, for example, showed no traces of H-3 (Eskom, 2019).

Following from the explanation of H-3 in groundwater given in ***Subsection 5.11.5.3***, the H-3 values indicate that sample GCS1 has a pre-1952 age. This is somewhat anomalous for an actively recharged unconfined aquifer and can be explained by upward mixing of Malmesbury Aquifer groundwater due to lowering of the head in the Sandveld Aquifer due to pumping from the Aquarius Wellfield. Boreholes E08, PBMR-BH and TW2 show a mixture of pre- and post-1952 water.

5.11.5.7 Groundwater Use

The town of Atlantis has been largely dependent on groundwater for its water supply since 1976. Groundwater was originally abstracted from the aquifer at 40 boreholes in the Witzand and Silwerstroom wellfields, softened at a water treatment plant and then distributed for domestic and industrial use (Parsons and Associates, 2005). Two basins situated in the dunes to the southwest of Atlantis serve as final retention ponds for stormwater run-off and provide for the artificial recharge of the aquifer some 500 m upgradient of the Witzand Wellfield (Tredoux, et al., 1999).

Intermediate quality (EC 60 – 80 mS/m) stormwater and treated domestic wastewater are discharged into Basin 7 (southern recharge basin), situated 4 km northeast (***Drawing 5.11.7***) of the site (Tredoux, et al., 2011). High quality (EC 40 – 60 mS/m) stormwater is diverted into Basin 12 (northern recharge basin) (Tredoux, et al., 2011). This artificial recharge counters the encroachment of naturally poorer quality groundwater (Tredoux, et al., 1999). Poorer quality (EC 170 – 180 mS/m) wastewater, including treated industrial effluent, is discharged into the coastal infiltration basins along the coastline (Tredoux, et al., 2011), 3 km north of the site. This poorer quality water cannot be used for recharge into the aquifer and does not meet the requirements of the DWA General Standard for discharge into the Donkergat River and is, therefore, disposed of as close to the coast as possible (Hobbs, 2005). Recharge into these coastal infiltration basins produces a subsurface hydraulic mound that acts as a barrier against seawater intrusion and increases the exploitable groundwater resource potential upgradient at the Witzand Wellfield (Parsons and Associates, 2005) and (Hobbs, 2005). The coastal recharge basins are fulfilling their function of building a positive hydraulic head along the coastline (Hobbs, 2005).

Groundwater abstraction from the Witzand and Silwerstroom wellfields was 14 ℓ/s (0.43 Mm^3/a) in 1977 (Ninham Shand and BKS, 1992), 270 ℓ/s (8.5 Mm^3/a) in 1998/1999 and 101 ℓ/s (3.2 Mm^3/a) in 2005, the latter solely from the Witzand Wellfield. Based on numerical modelling results, the sustainable 'fresh water' yield of the Witzand Wellfield is 184 ℓ/s (5.8 Mm^3/a) (Council for Scientific and Industrial Research, 1990).

Data received from the CCT in January 2019 (***Table 5.11.10***) indicate that the average annual abstraction from the Sandveld Aquifer at the Witzand and Silwerstroom wellfields for the period 1993 to 1998 was approximately 234 ℓ/s (7.387 Mm^3/a). For the period 1999 to 2018, however, the average annual abstraction was approximately 48 ℓ/s (1.508 Mm^3/a), which is significantly less than what was abstracted from 1993 to 1998. The reduced yields and the overall significantly reduced productivity of the two wellfields is a result of borehole clogging by naturally occurring precipitates (mainly iron compounds). The CCT is currently busy with borehole replacement and rehabilitation to remove the precipitates and clear the slotted casing to increase the borehole yields back to their originally determined sustainable yields. The CCT has recently re-drilled 22 boreholes and rehabilitated a further 12 boreholes, associated with the Witzand Wellfield. The design yield from the upgraded wellfield is 237 ℓ/s, slightly more than quoted in ***Table*** 5.11.10. The drilling of new production boreholes hasn't started yet, but it is planned to obtain an additional 127 to 162 ℓ/s (personal communication. C Lasher-Scheepers CCT, April 2020).

Table 5.11.10
Groundwater Abstraction from the Sandveld Aquifer at the CCT Witzand and Silwerstroom Wellfields from January 1993 to July 2018

Year	Witzand (m^3/a)	Silwerstroom (m^3/a)	Total (m^3/a)	Abstraction Rate (ℓ/s)
1993	4 978 481	1 232 518	6 210 999	197
1994	5 412 702	1 595 646	7 008 347	222
1995	5 470 436	2 009 866	7 480 301	237
1996	6 302 602	2 090 865	8 393 467	266
1997	6 672 571	1 400 284	8 072 855	256
1998	5 219 313	1 940 068	7 159 381	227
1999	1 452 321	1 065 134	2 517 455	80
2000	866 022	151 884	1 017 906	32
2001	1 095 075	16 647	1 111 722	35
2002	1 154 576	51 956	1 206 531	38
2003	1 997 761	71 794	2 069 555	66
2004	1 646 668	53 196	1 699 864	54
2005	2 153 928	126 746	2 280 674	72
2006	2 293 705	113 240	2 406 945	76
2007	2 105 085	101 580	2 206 665	70
2008	1 500 488	92 354	1 592 842	51
2009	636 524	110 045	746 569	24
2010	639 916	146 166	786 082	25
2011	708 652	241 089	949 741	30
2012	1 355 176	241 082	1 596 258	51
2013	1 258 017	209 541	1 467 558	47
2014	559 402	177 788	737 190	23
2015	308 360	77 604	385 964	12
2016	1 069 277	59 110	1 128 388	36
2017	2 707 981	220 469	2 928 450	93
2018*	1 123 520	208 535	1 332 055	42
Total	**60 688 557**	**13 805 207**	**74 493 764**	
Pre-1999 Average	**5 676 017**	**1 711 541**	**7 387 558**	**234**
Post-1998 Average	**1 331 623**	**176 798**	**1 508 421**	**48**

* January to June 2018

There are no detectable signs of any negative groundwater impacts caused by abstraction from the Atlantis Aquifer, and the Silwerstroom Spring is still flowing, with a discharge rate estimated to be 15.8 ℓ/s (0.5 Mm^3/a) in 1992

(Council for Scientific and Industrial Research, 1992). The CCT was unable to supply a more recent reading (pers. comm. C. Lasher-Scheepers, CCT, June 2020).

It was previously estimated that 16 ℓ/s of groundwater could be abstracted from the Aquarius Wellfield (Groundwater Consulting Services, 1996). These boreholes were initially drilled to supply water to the KNPS. However, as the groundwater is relatively high in salinity and desalination by reverse osmosis was then deemed not cost-effective, this use was abandoned (Eskom, 2006). Four of the wellfield boreholes (GCS1, GCS7, GCS9 and GCS10) were re-commissioned in early 2007 for game watering and irrigation purposes, as well as to supply the dam at the conservation offices. During 2017, after the CCT implemented water restrictions due to a severe drought, the boreholes of the Aquarius Wellfield were refurbished, re-tested and re-commissioning for water supply to a desalination plant for KNPS (Advisian, 2018). Based on a 12-hour pumping cycle for each borehole, a sustainable wellfield abstraction of 1 361 m^3/d was recommended (Advisian, 2018). This equates to 113.4 m^3/h (31.5 ℓ/s), which over a 24-hour/day schedule is equivalent to approximately 57 m^3/h (15.8 ℓ/s). A summary of borehole data collected by Advisian at the Aquarius Wellfield in 2017 is presented in ***<u>Table 5.11.11</u>***.

Table 5.11.11
Summary of Aquarius Wellfield Data in 2017 (After Advisian, 2018)

Borehole No.	Latitude	Longitude	Elevation (m amsl)	Depth (m bgl)	Depth (m amsl)	Rest Water Level (m bc)*	Rest Water Level (m amsl)	Sustain-able Yield (ℓ/s)	T (m^2/d)
GCS01	33.65441	18.43965	42	28.60	13.40	6.73	35.27	2.0	16
GCS02	33.65198	18.43871	46	32.43	13.57	11.64	34.36	3.0	22
GCS03	33.65013	18.43815	44	27.20	16.80	8.55	35.45	3.0	40
GCS04#	33.64774	18.43758	43	-	-	-	39.56	-	-
GCS05	33.64632	18.43727	43	24.66	18.34	5.44	37.56	5.0	56
GCS06	33.64511	18.43703	44	27.80	16.20	6.18	37.82	2.5	78
GCS07	33.64334	18.43772	46	26.30	19.70	2.54	43.46	3.0	75
GCS08	33.64153	18.43871	50	26.60	23.40	3.49	46.51	2.0	36
GCS09	33.64011	18.43940	52	27.70	24.30	3.33	48.67	5.0	134
GCS10	33.63865	18.43984	54	31.06	22.94	3.10	50.90	6.0	148

Borehole blocked – replacement recommended by Advisian
* m below collar

It should be noted that the test pumping was carried out between August and September 2017, i.e. during a severe drought, and that the borehole yields obtained were very similar to those during the original wellfield installation in 1996. This indicates that the primary aquifer is 'buffered' against climate extremes, most likely by its high storage capacity. There was also no measurable impact of pumping boreholes on water levels in other wellfield boreholes.

A number of surveys have been conducted in the vicinity of the site, e.g. in September 1999 (Africon, 2001), August and November 2004 (Parsons and Associates, 2005), September 2007 (SRK Consulting, 2007). Where possible, the position (Global Positioning System or GPS reading), depth, groundwater level, use, and yield were obtained, and a groundwater sample collected for chemical analysis. The January 2008 hydrocensus for this SSR was carried out in areas where little or no existing data were available i.e. in the suburb of Duynefontein. This hydrocensus was repeated in July 2017. A summary of previously collected (September 2007) hydrocensus data (boreholes sampled) is listed in ***Table 5.11.12,*** ***Table 5.11.13*** and detailed in ***Appendix 5.11.B***.

Groundwater is also used in the vicinity of the site as a source of water for smallholdings, brick making and sand mining (Africon, 2001). Groundwater is predominantly used for small-scale vegetable farming, water for horses and irrigation of commercial lawn. Reticulated municipal water is available to most smallholdings from a pipeline constructed in 2002, but municipal water is only used to a limited extent due to its relatively high cost.

There are approximately 1 000 erven in Duynefontein, of which about 75 per cent have wellpoints installed for garden irrigation purposes. Duynefontein is considered a high-income group area and typical water demand is estimated to be 1 800 ℓ/d per household (i.e. 450 ℓ/p/d for a four person household) (The Freshwater Consulting Group, 2007). The estimated breakdown of domestic water usage indicates that 35 per cent of water is used for garden irrigation (The Freshwater Consulting Group, 2007). Therefore, an average of some >0.01 ℓ/s (230 m^3/a) of groundwater per erf is abstracted via wellpoints from the primary aquifer, assuming gardens are irrigated each day. This equates to about 5.5 ℓ/s of groundwater being abstracted from the area south of the KNPS.

A summary of data collected during this SSR's 2008 hydrocensus is presented in ***Table 5.11.13***, while that collected during the 2017 repeat hydrocensus is presented in ***Table 5.11.14***. Details are also listed in ***Appendix 5.11.B***.

Table 5.11.12
Summary of Previous Hydrocensus Data: Sampled Boreholes

Borehole No.	Location	Source Type	Aquifer Type	Rest Water Level (m bgl)	Electrical Conductivity (mS/m)	pH
E08	Nuclear-1	Borehole	Sandveld	1.48	148	7.7
GCS01	Aquarius Wellfield	Borehole	Sandveld	6.37	247	7.3
PBMR-BH	PBMR Site	Well	Sandveld	NA	250	7.4
TW2	KNPS	Piezometer	Sandveld	4.46	98	8.5

NA = indicates that information could not be obtained

Table 5.11.13
Summary of Hydrocensus Data: January 2008

Borehole No.	Location	Source Type	Aquifer Type*	Rest Water Level** (m bgl)	Electrical Conductivity (mS/m)	pH
10HAMK	Duynefontein	Wellpoint	NA	NA	205	7.6
10HUMA	Duynefontein	Wellpoint	Sandveld	NA	268	7.5
10PELI	Duynefontein	Wellpoint	Sandveld	NA	240	7.6
11-STD	Duynefontein	Wellpoint	NA	NA	196	7.4
12DBAD	Duynefontein	Wellpoint	Sandveld	NA	137	7.6
13SEAG	Duynefontein	Wellpoint	Sandveld	NA	150	7.4
1063/18	Duynefontein East	Borehole	NA	NA	1 331	6.8
20STRD	Duynefontein	Wellpoint	Sandveld	NA	141	7.6
23HERN	Duynefontein	Wellpoint	NA	NA	69	7.2
25CHRL	Duynefontein	Wellpoint	Sandveld	NA	141	7.6
25HORN	Duynefontein	Wellpoint	NA	NA	310	7.2
4HAMKP	Duynefontein	Wellpoint	Sandveld	NA	NA	NA
5EAGLE	Duynefontein	Wellpoint	NA	NA	NA	NA
8DIBAD	Duynefontein	Borehole	NA	NA	246	7.8
86CHAR	Duynefontein	Wellpoint	NA	NA	172	7.8
9780	Duynefontein	Wellpoint	Sandveld	NA	340	7.2
9TARNT	Duynefontein	Wellpoint	NA	NA	464	7.7
1063/7	Duynefontein	Borehole	NA	NA	NA	NA
1063/6	Duynefontein	Borehole	NA	NA	510	7.1
1063/24A	Thobeka Stables	Wellpoint	Sandveld	NA	212	6.3
19SEAG	Duynefontein	Wellpoint	NA	NA	NA	NA
1063/13	Duynefontein	Borehole	NA	NA	NA	NA
1063/16	Duynefontein	Borehole	NA	NA	NA	NA

NA = indicates that information could not be obtained.
* Aquifer indicated where known, but all wellpoints are presumed to tap the Sandveld Aquifer
** Refers to the natural groundwater level in a borehole not influenced by abstraction or artificial recharge.

Table 5.11.14
Summary of Hydrocensus Data: July 2017

Borehole No.	Location	Source Type	Aquifer Type*	Rest Water Level** (m bgl)	Electrical Conductivity (mS/m)	pH
11 DUIK	Duynefontein	Wellpoint	Sandveld	NA	278	7.20
23 HERN	Duynefontein	Wellpoint	Sandveld	NA	144	7.40
22 HERN	Duynefontein	Wellpoint	Sandveld	NA	358	7.30
2 HERN	Duynefontein	Wellpoint	Sandveld	NA	276	7.40
80 CHAR	Duynefontein	Wellpoint	Sandveld	NA	297	7.10
1063/18	Duynefontein East	Borehole		NA	188	6.50
1063/24A	Thobeka Stables	Wellpoint	Sandveld	NA	221	5.90
8 KORH	Melkbostrand	Wellpoint	Sandveld	NA	280	7.40
MV1	Duynefontein	Wellpoint	Sandveld	NA	1 165	7.10
OL1	Ogieskraal	Borehole	NA	NA	1 264	6.80
WP 212	Witzand	Borehole	NA	4.62	45	7.70
East1	Duynefontein	Borehole	NA	4.23	398	8.80
G33464	Klein Springfontein	Borehole	NA	19.55	127	7.40
WP 171A	Duynefontyn	Borehole	NA	4.40	132	7.50
W 34019	Klein Springfontein	Borehole	NA	5.58	103	8.20
2 GAN	Duynefontein	Wellpoint	Sandveld	NA	NA	NA
4 HAMK	Duynefontein	Wellpoint	Sandveld	NA	NA	NA

NA = indicates that information could not be obtained.
* Aquifer indicated where known, but all wellpoints are presumed to tap the Sandveld Aquifer
** Refers to the natural groundwater level in a borehole not influenced by abstraction or artificial recharge.

All boreholes from the NGA in the Witzand, Aquarius and Silwerstroom wellfields on and surrounding the site from previous hydrocensus work, from the 2008 and 2017 hydrocensuses and this SSR drilling programme are shown in ***Drawing 5.11.7***.

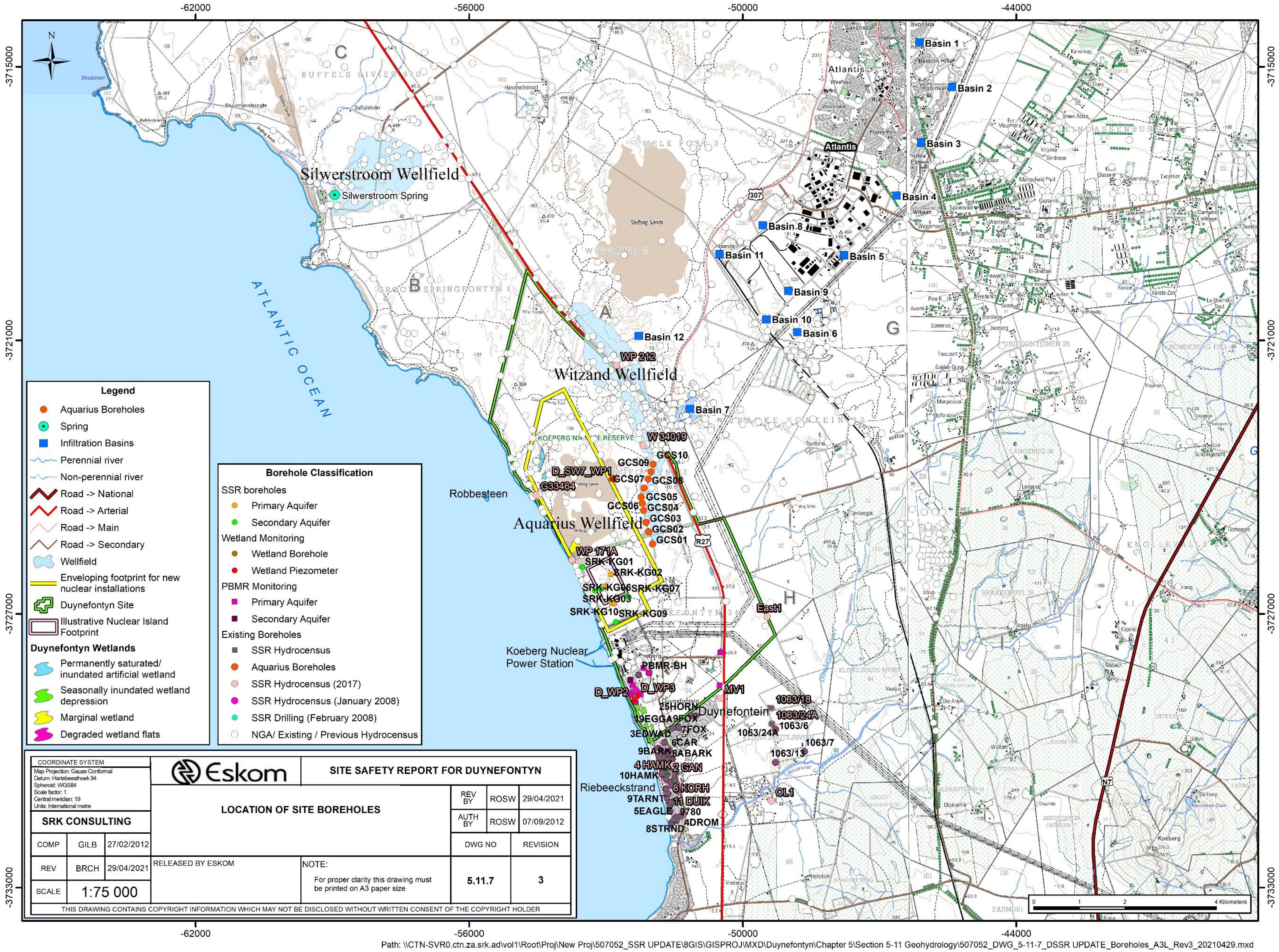
Ecosystems

The only area in the vicinity of the site where the terrain is sufficiently low-lying to support significant areas of wetland habitat is found 1.5 km north of the site. The 'slack' areas between a series of low-lying east-west oriented dunes give rise to a mosaic system of dune-slack wetlands (The Freshwater Consulting Group, 2008). The wetland areas are shown in all drawings and a more detailed description is included in ***Section 5.3*** of this SSR.

These wetlands are fed primarily by seasonal fluctuations in the water table, forming pools of shallow, brackish water during winter, which dry up during the low-rainfall summer months when the water table drops. Wet season salinities in the wetlands are elevated, as a result of marine influences such as sea mists and on-shore winds and saline evaporite residues on the surface that are dissolved in the rising water table. The wetlands are of high local and regional ecological importance, although their similarity to other wetlands north of the site has not yet been established (The Freshwater Consulting Group, 2008).

A series of coastal infiltration basins has been excavated between the dunes as part of the Atlantis water supply system and may be linked to an increase in seepage and deterioration of the limestone cliffs along a section of nearby coastal shoreline (The Freshwater Consulting Group, 2008) and (Mawatsan, 2007). These basins are highly artificial habitats, comprising deep, permanent, open-water bodies, vegetated by species that thrive under conditions of nutrient enrichment (The Freshwater Consulting Group, 2008) and (Mawatsan, 2007). They play an important role in terms of providing a hydraulic barrier for the protection of the Atlantis Aquifer from seawater intrusion (The Freshwater Consulting Group, 2008).

Several short, ephemeral streams flow directly towards the Atlantic Ocean in the vicinity of the site. Most of these streams ‘disappear’ into the flat sandy areas near the coast or cannot maintain open river channels across the coastal dunes (Department of Water Affairs and Forestry, 1980). No streams/rivers flow through the site and the closest significant drainage channel is the Sout River 5 km south of the site and its largest tributary, the Donkergat River, which discharges into the ocean at Melkbosstrand (Department of Water Affairs and Forestry, 1980). The Sout River is 3.5 km at its nearest point to KNPS and 5 km at its nearest point to the Nuclear-1 footprint. The Donkergat River is 3.5 km from KNPS and 4.5 km from the Nuclear-1 footprint.


Silwerstroom Wellfield
Silwerstroom Spring
Witzand Wellfield
Aquarius Wellfield
ATLANTIC OCEAN
Robbesteen
Koeberg Nuclear Power Station
Duynefontein
Riebeeckstrand
Atlantis
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Basin 12
Legend
Aquarius Boreholes
Spring
Infiltration Basins
Perennial river
Non-perennial river
Road -> National
Road -> Arterial
Road -> Main
Road -> Secondary
Wellfield
Enveloping footprint for new nuclear installations
Duynefontyn Site
Illustrative Nuclear Island Footprint
Duynefontyn Wetlands
Permanently saturated/ inundated artificial wetland
Seasonally inundated wetland depression
Marginal wetland
Degraded wetland flats
Borehole Classification
SSR boreholes
Primary Aquifer
Secondary Aquifer
Wetland Monitoring
Wetland Borehole
Wetland Piezometer
PBMR Monitoring
Primary Aquifer
Secondary Aquifer
Existing Boreholes
SSR Hydrocensus
Aquarius Boreholes
SSR Hydrocensus (2017)
SSR Hydrocensus (January 2008)
SSR Drilling (February 2008)
NGA/ Existing / Previous Hydrocensus
COORDINATE SYSTEM
Map Projection: Gauss Conformal
Datum: Hartebeesthoek 94
Spheroid: WGS84
Scale factor: 1
Central meridian: 19
Units: International metre
SRK CONSULTING
Eskom
SITE SAFETY REPORT FOR DUYNEFONTYN
LOCATION OF SITE BOREHOLES
REV BY ROSW 29/04/2021
AUTH BY ROSW 07/09/2012
COMP GILB 27/02/2012
REV BRCH 29/04/2021
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5.11.6 Site Specific Description of Aquifers

There are two aquifers present at the site, viz.:

- Aquifer 1: Primary Sandveld Aquifer (upper, intergranular);
- Aquifer 2: Malmesbury Aquifer (basal, fractured-rock).

The distribution of these aquifers is presented in ***Drawing*** ***5.11.3*** along with the main points of groundwater abstraction as of June 2018. The primary aquifer overlies the fractured Malmesbury Aquifer at the site, separated by a clay horizon of varying thickness termed the Malmesbury Aquitard.

5.11.6.1 Aquifer 1: Primary Intergranular Sandveld Aquifer

Regionally, the primary aquifer comprises six geological formations belonging to the Sandveld Group, namely the Elandsfontyn, Varswater, Velddrif, Langebaan, Springfontyn and Witzand formations. The lithostratigraphy of the Sandveld Group is shown in ***Table 5.11.1***. The sand thickness varies considerably with the Elandsfontyn Formation reaching a maximum thickness of between 40 and 70 m east of Langebaan Lagoon (Johnson, et al., 2006). Near Atlantis, virtually all production boreholes draw groundwater from the medium-grained quartz sand horizons of the Springfontyn Formation (Tredoux, et al., 1999), because it is usually the thickest formation present. The Varswater Formation is less significant thickness-wise, and its development is limited to palaeo-estuarine depressions near the coast (Johnson, et al., 2006).

The local Atlantis Aquifer is an economically viable municipal water resource further inland at the Witzand and Aquarius wellfields. However, the total thickness (14 to 27 m) and saturated thickness of *c*.12 to *c*.25 m and finer grain size, limits its viability beyond local supply (e.g. start-up construction) in the site area.

The aquifer comprises calcareous aeolian sand containing minor organic matter and variable shelly material in the upper portion. This late Pleistocene to Holocene-age aeolianite contains lenses of calcrete and is between 1 and 13 m in thickness at the site. A discontinuous gravel/coarse sand layer occurs below the aeolian sand and calcrete. This layer is equivalent to the shallow marine Veldrift pebble layer and is composed of gravel, calcrete nodules and cemented shell fragments in a sand and clay matrix.

A clay layer occurs at the base of the gravel layer in four of the site boreholes (SRK-KG1, -KG2, -KG5 and -KG9) and is composed of 3 to 10 m of shallow marine/estuarine clay. The base of the primary aquifer on site comprises a variable layer of dense fine to medium grained sand with shell fragments, the Varswater Formation.

Schematic geohydrological sections through the site and surrounds and site are shown in ***Figure 5.11.23*** (marked as ① and ②, respectively) under the conceptual model discussed in ***Subsection 5.11.8***.

Hydraulic Properties

Pumping tests and double-ring infiltrometer tests have previously been conducted on the Atlantis Aquifer to determine the hydraulic properties (Department of Water Affairs and Forestry, 1982), (Council for Scientific and Industrial Research, 2000), (Groundwater Consulting Services, 1996) and (Council for Scientific and Industrial Research, 1993). Based on these tests, transmissivity (T) values for the Atlantis Aquifer vary between 10 and 1 400 m^2/d. Further to the south, with an increase in the percentage of fine material and decrease in the saturated thickness of the sands, the T values decrease. At the KNPS, T values of the primary aquifer were estimated to be *c.*40 m^2/d (Council for Scientific and Industrial Research, 2000). At the Aquarius Wellfield calculated T values range from 15 to 100 m^2/d (Groundwater Consulting Services, 1996). Along the coastline at the western edge of the site, a T value of 75 m^2/d was obtained (Council for Scientific and Industrial Research, 1993).

Analyses of test pumping results for the SSR boreholes drilled on-site indicate T values ranging from 16 to 140 m^2/d (***Table 5.11.15***), i.e. at the lower end of the range, mainly reflecting the limited thickness and smaller grain size of the aquifer in this area.

Hydraulic conductivity (K) for the various formations of the Atlantis Aquifer was found to range between 13 and 35 m/d, except for the finer grained Varswater Formation (1 to 3.5 m/d) (Groundwater Consulting Services, 1996). The average K near the planned PBMR DPP site was found to be 2.6 m/d (Council for Scientific and Industrial Research, 2000), with the more permeable, upper layers of the primary aquifer ranging between 3 and 10 m/d, and the underlying, less permeable layers ranging between 0.004 and 0.005 m/d. A K value of 25 m/d was reported for the primary aquifer closer to Atlantis (Department of Water Affairs and Forestry, 1982). Along the coastline at the western edge of the site, a K value of 12 m/d was obtained (Council for Scientific and Industrial Research, 1993). Double ring infiltrometer tests were used to determine vertical K at the artificial recharge basin northeast of the site (Council for Scientific and Industrial Research, 1993). Based on data derived from the seven infiltrometer tests, vertical K ranges from 8 to 31 m/d. These are somewhat anomalous results as vertical K is usually an order of magnitude lower than horizontal or radial K. However, it is noted that K varies significantly over the study area and is roughly equivalent in the horizontal/radial and vertical directions (Council for Scientific and Industrial Research and City of Cape;, 2017) and this will be discussed further under flow modelling.

K values (horizontal) obtained from testing of the SSR boreholes ranged from 0.9 to 5.6 m/d (***Table 5.11.15***), i.e. at the lower end of the range, as with T. This was also found to be the case with calibration of the Council for Scientific and Industrial Research numerical flow model of the Atlantis Aquifer (Council for Scientific and Industrial Research, 2017).

Specific yield (Sy) was determined to be between 0.04 (4 per cent) and 0.25 (25 per cent) (Council for Scientific and Industrial Research, 2000), (Council for Scientific and Industrial Research, 2017), (Council for Scientific and Industrial Research and City of Cape;, 2017), (Department of Water Affairs and Forestry, 1982) and (Council for Scientific and Industrial Research, 1990) for the Atlantis Aquifer.

Specific yield values determined from the SSR boreholes range from 0.11 to 0.30 (***Table 5.11.15***), i.e. 11 to 30 per cent, which are typical ranges for this type of aquifer. They are also broadly within the bounds of previous research findings in this regard, e.g. 0.17 or 17 per cent (Council for Scientific and Industrial Research, 2017).

Table 5.11.15
Summary of the Sandveld Aquifer Hydraulic Parameters Derived from SSR Boreholes

Borehole No.	Transmissivity T (m^2/d)	Specific yield (Sy)	Saturated Thickness (m)	Calculated Hydraulic Conductivity K (m/day)	Assumed* Porosity (%)	Max Test Yield (ℓ/s)	Potential Sustainable Yield (ℓ/s)	Comments
SRK-KG2	22	0.20	25.00	0.9	20	5.1	2.0	Sustainable yield estimated from Calibration Graph. T & Sy determined by using the FC-Non Linear Method
SRK-KG5	140	0.30	25.00	5.6	20	5.1	3.0	Sustainable yield estimated from Calibration Graph. T & Sy determined by using the FC-Non Linear Method
SRK-KG8	57	0.11	21.00	2.7	20	7.0	2.0	Sustainable yield calculated with FC, Cooper-Jacob & Theis Methods
SRK-KG10	16	0.25	17.00	0.9	20	5.4	1.0	Sustainable yield estimated from Calibration Graph. T & S determined by using the FC-Non Linear Method
Average	59	0.22	22.00	2.5	20	5.6	2.0	
Median	40	0.23	23.00	1.8	20	5.3	1.5	

Note: K was calculated by dividing T by saturated thickness, i.e. aquifer thickness. Aquifer thickness = Borehole depth minus water level. * Approximate value based on the porosity range in (Council for Scientific and Industrial Research and City of Cape;, 2017)

A summary of the hydraulic parameters for the Sandveld Aquifer, as derived from test pumping analysis from the SSR boreholes, is presented in ***Table*** 5.11.15 and discussed further in the numerical flow modelling (***Subsection 5.11.8***) and specialist modelling report (***Appendix 5.11.J***).

Borehole Yields

Yields of >10 ℓ/s are obtained from production boreholes in the Witzand and Silwerstroom wellfields. Replacement boreholes in the Witzand Wellfield drilled during 1996 yielded between 16 and 18 ℓ/s (Council for Scientific and Industrial Research, 1996). Boreholes drilled to the northeast of the site, at a candidate regional landfill site for the CCT, yielded >5 ℓ/s (Parsons and Associates, 2006). Two boreholes drilled during 1991 by SRK Consulting along the northern boundary of the site yielded 1.7 and 4.2 ℓ/s (SRK Consulting, 1995). Ten boreholes drilled to depths of between 25 and 33 m for the Aquarius Wellfield yielded between 2 and 6 ℓ/s (Groundwater Consulting Services, 1996). More recent yield testing of these boreholes has indicated similar sustainable yields (Advisian, 2018).

Maximum test pumping yields obtained for the four SSR boreholes drilled into the primary aquifer ranged from 5.1 to 7.0 ℓ/s (***Table 5.11.15***). These yields indicate that the site primary aquifer could contribute to the start-up and construction water supply requirements. This scenario is further investigated in the modelling, ***Subsection 5.11.7***.

Groundwater Levels

Groundwater levels measured in SSR boreholes in the Sandveld Aquifer are shown in ***Table 5.11.16***. These water levels were measured after drilling (March 2008) and monitoring from May 2008 to May 2020. Data logger equipped boreholes D-SW7-MR3 and G33444 have been monitored hourly since February 2010 whilst logger equipped borehole SRK-KG10 has been monitored hourly since June 2008. All these boreholes represent the water level in the unconfined primary Sandveld Aquifer. Depth to groundwater at the illustrative footprint measured at SRK-KG10 varies between 2.18 and 3.75 m bgl, i.e. a maximum variation of 1.57 m. Overall average variation in the Sandveld Aquifer is 1.08 m whilst overall variation in the logger equipped boreholes is 1.43 m. Water levels did not reach sea level during test pumping and this was also the case with the Aquarius Wellfield boreholes, which were all drilled to the Malmesbury bedrock, the upper surface of which is *c*.-5 to *c*.-13 m below mean sea level at the coast and in the footprint area.

Table 5.11.16
Groundwater Levels for Sandveld Aquifer DSSR Monitoring Boreholes

Borehole No.	Depth (m)	Surface Elevation (m amsl)	Minimum Water Level Depth (m bgl)	Maximum Water Level Depth (m bgl)	Average Water Level Depth (m bgl)	Maximum Water Level Variation (m)
SRK-KG2	26.76	16.93	1.42	2.66	1.98	0.61
SRK-KG5	26.39	17.00	4.14	4.74	4.50	0.59
SRK-KG8	20.45	16.67	3.54	4.50	4.04	0.96
SRK-KG10#	20.34	16.30	2.18	3.75	3.01	1.57
D-SW7-MR3##	10.50	32.92	0.30	1.35	0.91	1.05
G33444##	29.00	33.60	2.63	4.30	3.79	1.67
Average						1.08
Average Loggers						1.43

Values derived from monitoring data collected from March 2008 to May 2020.
data logger in this borehole – data from June 2008 to July 2020
data loggers in these boreholes – data from February 2010 to July 2020

A hydrograph of the groundwater level monitored by means of a continuous data logger in SRK-KG10 is shown in ***Figure 5.11.11***. The graph shows groundwater levels from June 2008 until January 2020 and monthly rainfall measured at the on-site Koeberg meteorological station (station no. G2E001). The graph shows a variation of groundwater level linked to rainfall, with an increase in water level in winter/spring as significant rainfall events become more frequent and a decrease in water level during dryer periods (summer). Distinct high rainfall events in August 2008, December 2009, June 2013 and August 2013 show individual peaks in water level rise indicating high rainfall events will affect water levels on site and indicate a rapid response to recharge, as would be expected in areas with a shallow unconfined water table. Average wet-dry season water level variation is *c*.0.6 m. During the drier summer months from January to May, a definite drop in water level occurs due to a lack of recharge and natural discharge to the ocean.

The effect of one-day rainfall events on the water level is illustrated in ***Figure*** 5.11.12. A one-day rainfall of 35 mm recorded on 9 June 2008 resulted in a *c*.0.40 m rise in the water table over approximately 10 days. The effects of high monthly rainfall are shown particularly in 2013, 2014, 2016 and 2018. The effects of lower rainfall in 2009, 2010, 2011 and 2012 compared to 2008 and 2013 can be seen in the lower peak water level for 2009 to 2012. The low rainfall (severe drought according to the SPI method) of 2017 & 2018 resulted in the lowest water level of the 12-year monitoring period in 2020.

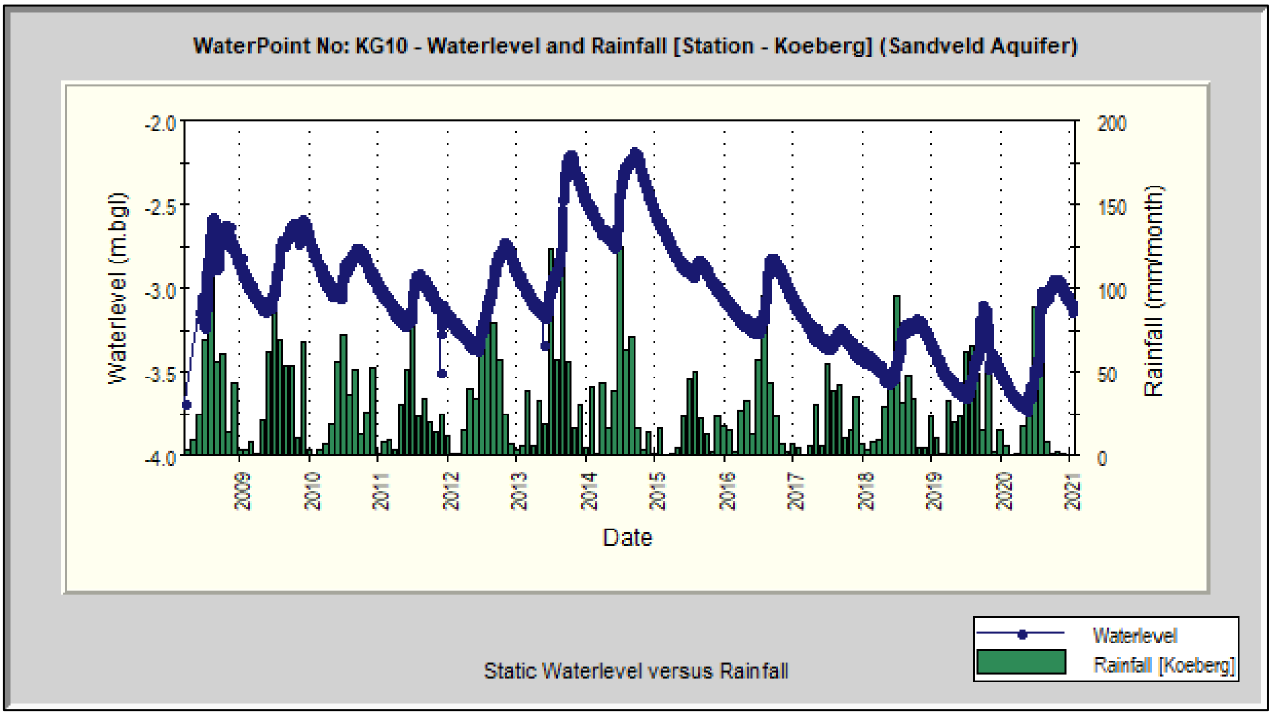


Figure 5.11.11
Hydrograph versus Monthly Rainfall: SRK-KG10 (Sandveld Aquifer)

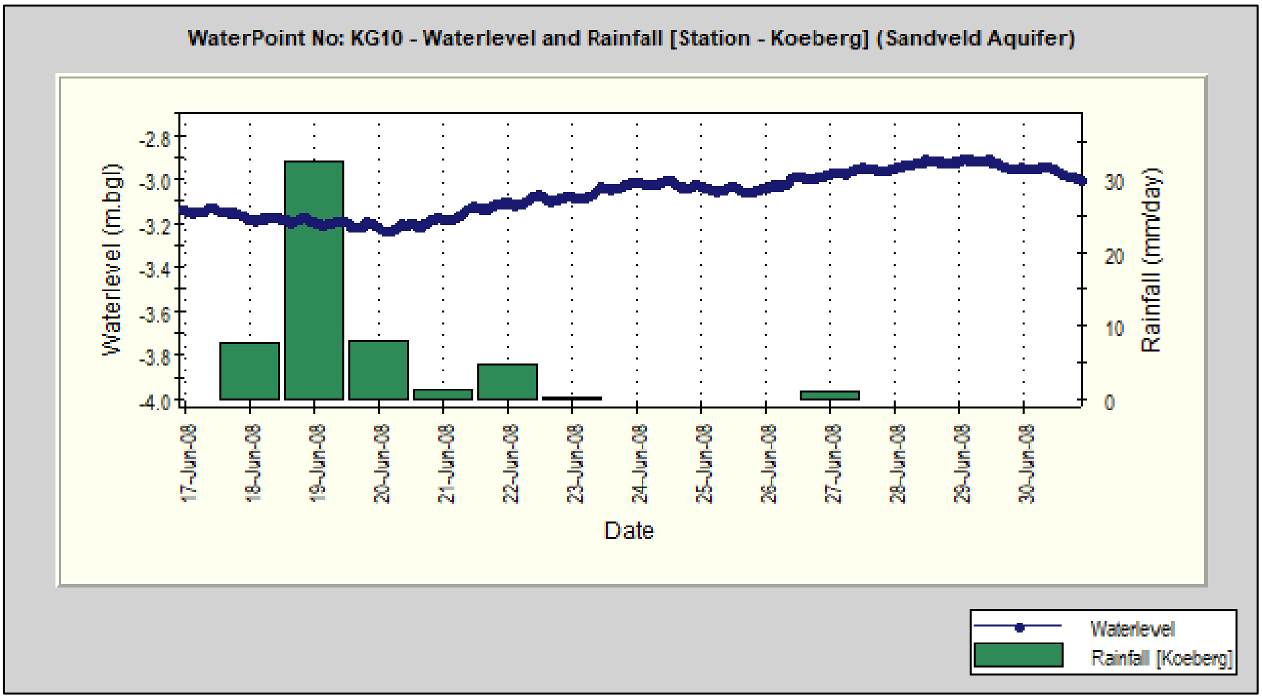


Figure 5.11.12
Hydrograph versus Daily Rainfall over Period 17-Jun-08 to 30-Jun-08 at SRK-KG10 (Sandveld Aquifer)

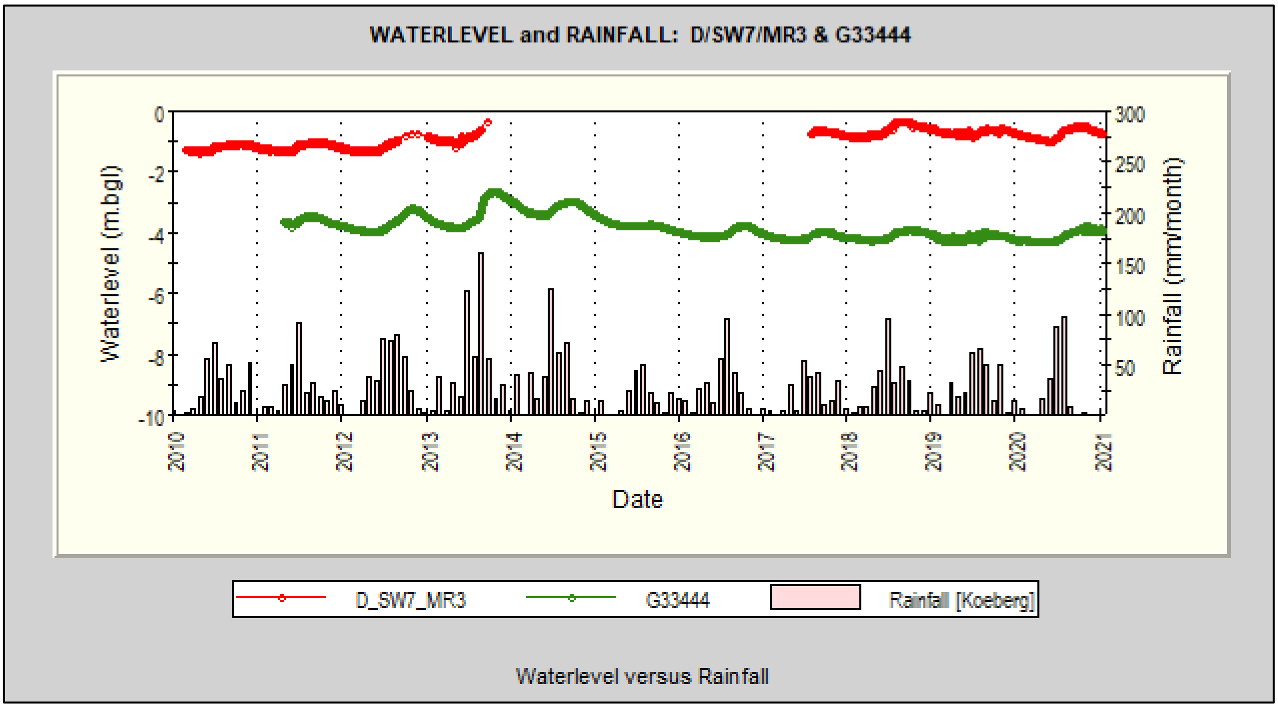


Figure 5.11.13
Hydrograph versus Monthly Rainfall at D-SW7-MR7 and G33444 (Sandveld Aquifer)

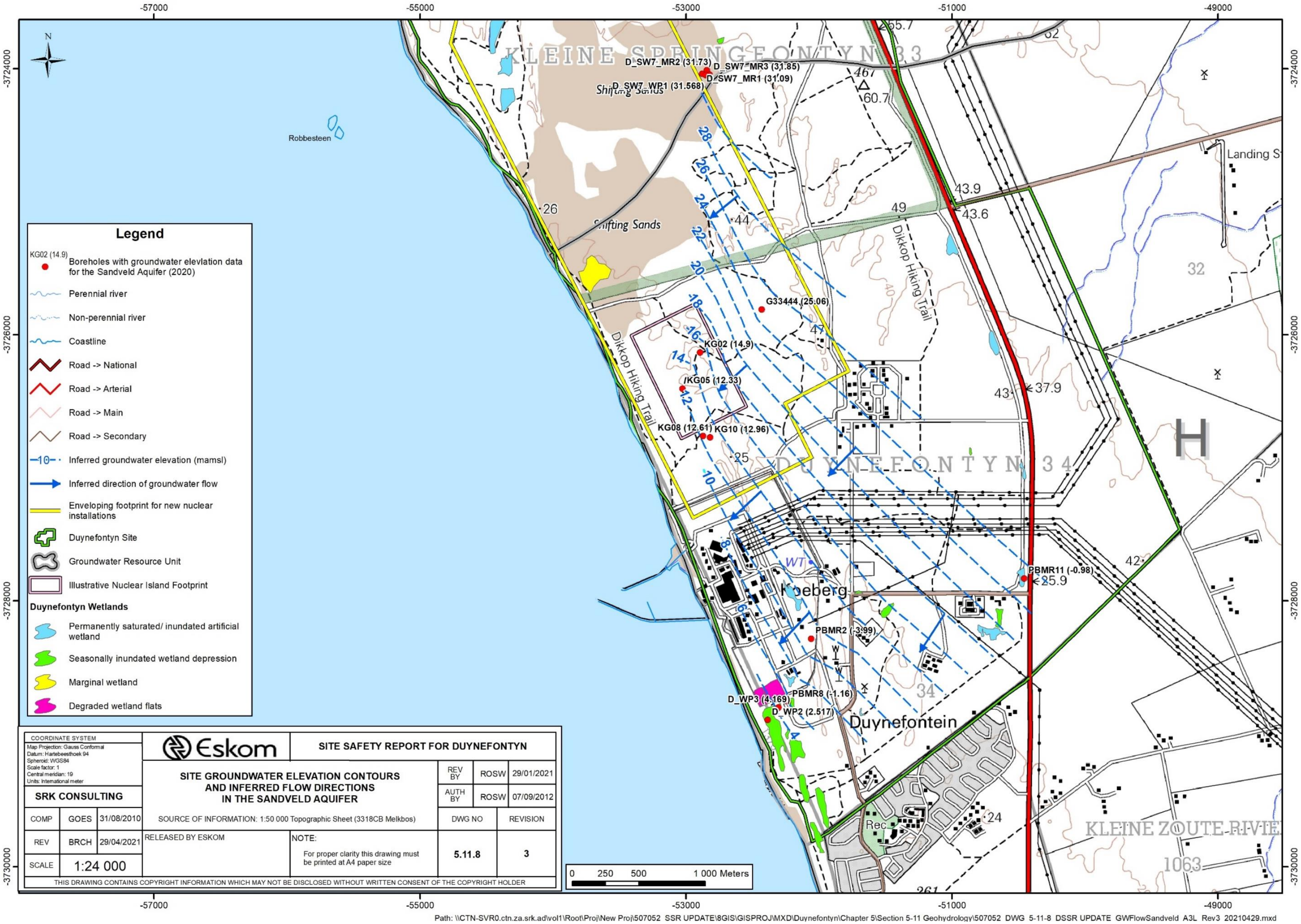
Similar water level variations are seen at the two other monitoring boreholes (D-SW7-MR3 and G33444) equipped with automatic recorders (***Figure*** 5.11.13).

Groundwater levels and interpolated elevation contours (m amsl) for the site and surrounding area are shown in ***Drawing 5.11.8***. The contours indicate that the main groundwater flow direction is in a southwesterly to westerly direction, i.e. towards the coast. The spacing of the contours shows some narrowing towards the coast nearing the boundary of the Atlantic Ocean and some widening inland, probably as a result of the thickening of the aquifer in this direction (higher T).

Water level data obtained from SSR observation borehole SRK-KG5 during the test pumping of SRK-KG4, which is located 94 m to the west and is drilled into the Malmesbury Aquifer, indicate connectivity between the Malmesbury and Sandveld aquifers, as previously indicated. A drawdown (over and above any existing trends) of 0.92 m was observed in SRK-KG5 at the end of the 72-hour constant yield test.

Apart from the influence of rainfall recharge on groundwater levels, certain man-made features associated with the nuclear installation(s), such as the proposed stormwater retention ponds, could influence groundwater levels. However, such effects (see ***Section 5.10*** of this SSR) are likely to be insignificant as these ponds will be lined and there will be relatively small volumes of surface water run-off created during storm events (small catchments and high infiltration).

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 indicated (see ***Section 5.9*** of this SSR) a possible rise in sea level of about 2.0 m by 2100, with an additional 15 per cent added for regional variation giving 2.3 m (Intergovernmental Panel on Climate Change, 2019). The position of the new coastline resulting from this expected rise has been estimated using GIS-based techniques and is presented in ***Drawing 5.11.9***. The possible impact of this sea level rise on site groundwater levels is covered in ***Subsection 5.11.7***.



KLEINE SPRINGFONTYN 33
DUYNEFONTYN 34
KLEINE ZOUTE RIVIER
Robbesteen
Shifting Sands
Dikkop Hiking Trail
Koeberg
Duynefontein
Landing S
D_SW7_MR2 (31.73)
D_SW7_MR3 (31.85)
D_SW7_MR1 (31.09)
D_SW7_WP1 (31.568)
G33444 (25.06)
KG02 (14.9)
KG05 (12.33)
KG08 (12.61)
KG10 (12.96)
PBMR11 (-0.98)
PBMR2 (-3.99)
PBMR8 (-1.16)
D_WP3 (4.169)
D_WP2 (2.517)
Legend
KG02 (14.9) Boreholes with groundwater elevlation data for the Sandveld Aquifer (2020)
Perennial river
Non-perennial river
Coastline
Road -> National
Road -> Arterial
Road -> Main
Road -> Secondary
Inferred groundwater elevation (mamsl)
Inferred direction of groundwater flow
Enveloping footprint for new nuclear installations
Duynefontyn Site
Groundwater Resource Unit
Illustrative Nuclear Island Footprint
Duynefontyn Wetlands
Permanently saturated/ inundated artificial wetland
Seasonally inundated wetland depression
Marginal wetland
Degraded wetland flats
COORDINATE SYSTEM
Map Projection: Gauss Conformal
Datum: Hartebeesthoek 94
Spheroid: WGS84
Scale factor: 1
Central meridian: 19
Units: International meter
SRK CONSULTING
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SITE SAFETY REPORT FOR DUYNEFONTYN
SITE GROUNDWATER ELEVATION CONTOURS AND INFERRED FLOW DIRECTIONS IN THE SANDVELD AQUIFER
REV BY ROSW 29/01/2021
AUTH BY ROSW 07/09/2012
COMP GOES 31/08/2010
REV BRCH 29/04/2021
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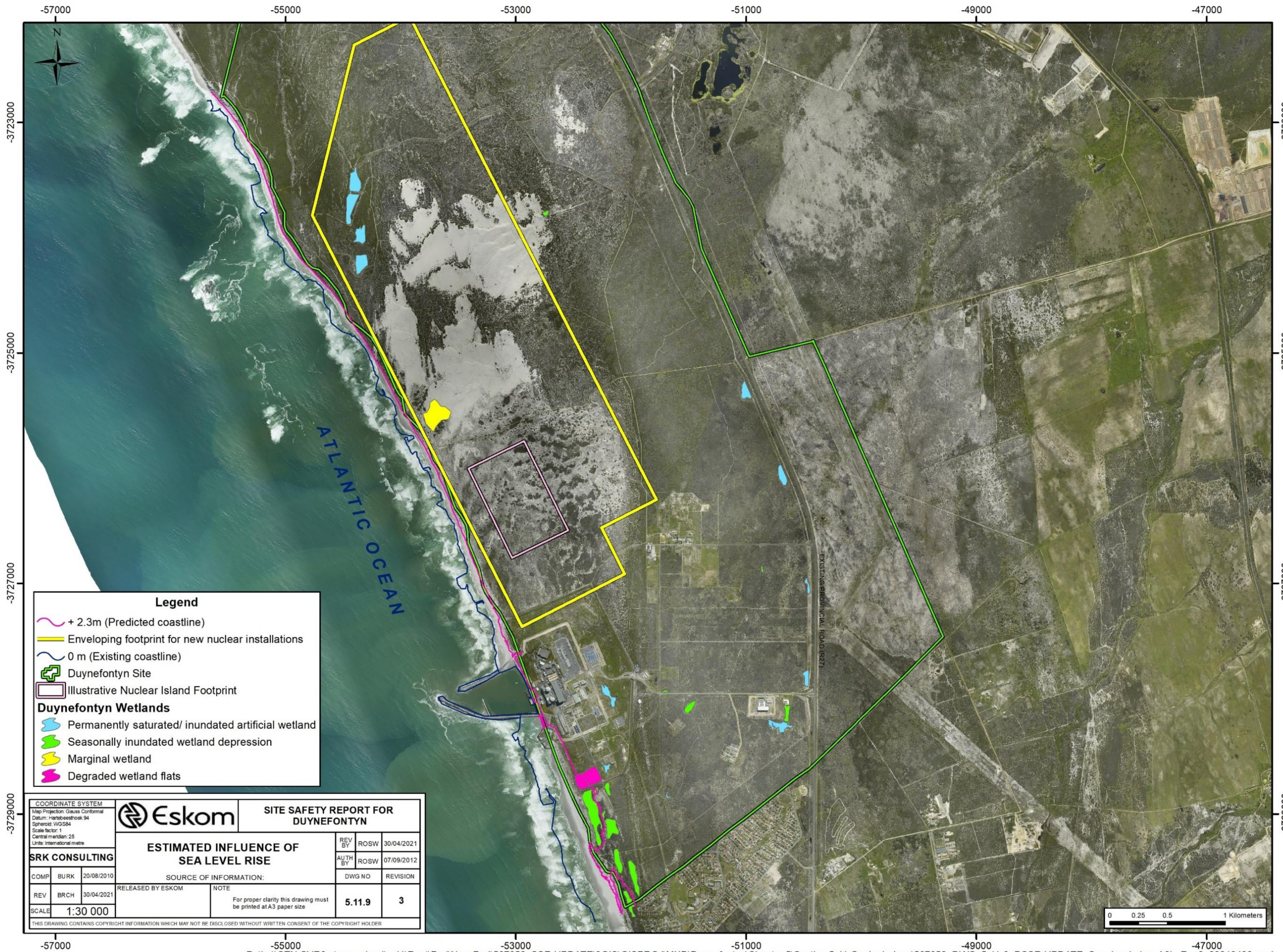

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Groundwater Quality

Down-hole EC and pH profile logs were run in the yield-tested SSR borehole SRK-KG8. Measured EC values varied from 86 to 195 mS/m and the pH values ranged from 7.1 to 7.6, i.e. neutral to slightly alkaline. The salinity and pH variation during the constant yield test for SRK-KG8 is shown in ***Figure 5.11.14***. The EC and pH graph indicates that after initial pumping the EC and pH stabilise at 194 mS/m and 7.5, respectively. There is no indication of the freshwater-saline water interface zone that should theoretically be present at the coast as none of the boreholes have been drilled deep enough. The fresh/saline water interface in an aquifer can be estimated by using the Ghyben-Herzberg relationship (Verrjuit, 1968), which states that the depth of the interface (in m) is equal to the height of water level in m amsl x 40. In SRK-KG10 at the provisional new installation(s) footprint, the water table averages about 17.50 m amsl, so the theoretical depth to the interface is about 700 m, i.e. well below the base of the Sandveld Aquifer and any possible influence on nuclear installation foundations.

The chemical analyses of samples from the primary aquifer over thirteen monitoring rounds are listed in ***Table 5.11.17*** and Piper plots of water samples taken from two selected SSR monitoring boreholes at the illustrative nuclear power plant footprint for the May 2008 to May 2020 monitoring rounds are shown in ***Figure 5.11.15***. These plots show a dominant NaCl character for SRK-KG8 and a mixture of NaCl and $Ca(HCO_3)_2$ character for SRK-KG2, typical of coastal aquifers.

The Langelier Saturation Indices vary from 0.21 to 0.32, indicating that this groundwater is likely to cause scaling (some minor coating). Sulfate, which corrodes ordinary concrete when present in concentrations >200 mg/ℓ, ranges from 44 to 77 mg/ℓ and the corrosion risk to foundations is therefore considered to be low. The Larson-Skold corrosion indices [(Roberge, 2000) and see box below] for mild steel for groundwater sampled from boreholes in the Sandveld Aquifer range from 1.4 to 5.8, with a median of 2.6, which indicates that a tendency towards high corrosion rates should be expected. Given these indices and the coastal environment, use of corrosion resistant materials must be considered in the nuclear installation(s) design[8]. The effect of groundwater on the soil/cement base-mat at KNPS is monitored as part of a groundwater protection programme (Eskom, 2020).

[8] Film refers to natural or added constituents in water that form a protective coating on exposed areas, e.g of a cooling system.

Index <0.8:	**chlorides and sulfate probably will not interfere with natural film formation;**
0.8> index <1.2:	**chlorides and sulfates may interfere with natural film formation. Higher than desired corrosion rates might be anticipated;**
Index >1.2:	**the tendency towards high corrosion rates of a local type should be expected as the index increases.**

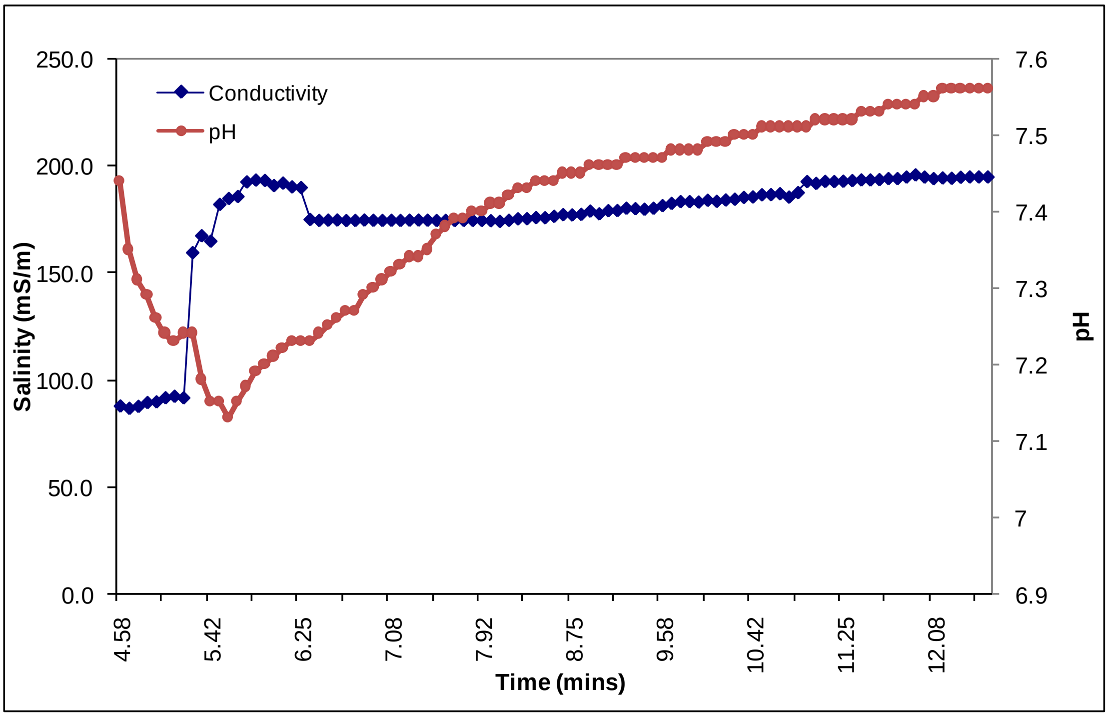


Figure 5.11.14
EC and pH Variation: SRK-KG8

Table 5.11.17
Chemical Analyses: Sandveld Aquifer Monitoring Boreholes

Borehole No.	Date	Ca	Mg	Na	K	Alkalinity as $CaCO_3$	Cl	SO_4	NO_3 as N	F	NH_4 as N	PO_4 as P	Fe	Mn	pH**	TDS	EC
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	pH units	mg/ℓ	mS/m
KG02	20/05/2008	98.0	21.0	107.0	4.0	236	205	58	<0.10	0.3	<0.1	NT	NT	NT	7.50	754	116
KG02	03/11/2008	87.0	14.8	95.0	9.1	222	179	49	0.80	0.4	<0.1	NT	NT	NT	8.00	709	109
KG02	04/05/2009	73.0	27.0	99.0	6.1	220	187	44	0.40	0.3	<0.1	NT	NT	NT	7.59	735	113
KG02	27/05/2011	77.0	22.0	128.0	7.0	213	198	61	0.40	0.2	<0.1	NT	<0.1	<0.02	7.90	728	112
KG02	28/11/2011	88.0	16.7	84.0	2.7	201	187	55	0.40	0.6	<0.1	NT	0.289	0.034	6.00	683	105
KG02	23/05/2012	79.0	24.0	118.0	5.1	226	191	85	0.60	0.3	<0.1	NT	<0.015	<0.001	7.69	735	113
KG02	26/11/2012	77.0	13.8	102.0	3.7	209	148	38	1.20	0.5	<0.1	NT	0.028	0.001	7.69	607	93
KG02	30/05/2013	86.0	18.5	109.0	4.0	210	229	41	1.50	0.2	0.39	NT	0.008	0.008	6.59	748	115
KG02	24/06/2017	81.7	23.5	105.7	4.0	211	192	58	0.88	0.9	NT	<0.05	<0.02	0.002	7.89	662	110
KG02	02/11/2017	89.1	23.9	104.5	3.0	208	180	60	2.10	0.4	NT	0.23	<0.02	0.004	7.90	667	112
KG02	11/04/2018	75.8	23.4	102.5	4.1	234	170	61	0.80	<0.3	NT	0.18	<0.02	0.006	6.94	714	100
KG02	16/10/2018	85.8	24.1	103.7	2.9	200	191	55	0.66	<0.3	NT	<0.05	<0.02	0.004	7.28	597	111
KG02	16/10/2019	80.7	22.2	91.6	4.0	218	180	57	1.02	0.4	NT	0.035	<0.02	0.003	7.76	643	133
KG08	20/05/2008	115.0	46.0	245.0	7.0	289	515	58	0.80	0.3	<0.1	NT	NT	NT	7.50	1469	226
KG08	03/11/2008	108.0	39.0	295.0	9.1	244	598	73	2.20	0.3	<0.1	NT	NT	NT	7.80	1671	257
KG08	04/05/2009	104.0	55.0	277.0	9.1	246	582	70	3.20	0.3	<0.1	NT	NT	NT	6.59	1352	208
KG08	27/05/2011	99.0	41.0	335.0	13.8	288	537	66	<0.10	0.2	<0.1	NT	<0.1	0.140	7.50	1502	231
KG08	28/11/2011	113.0	41.0	216.0	4.9	266	496	70	<0.10	0.4	0.10	NT	0.180	0.018	7.09	1456	224
KG08	23/05/2012	113.0	42.0	292.0	7.8	287	453	74	0.20	0.3	<0.1	NT	0.028	<0.001	7.59	1365	210
KG08	26/11/2012	106.0	39.0	289.0	6.5	270	443	63	<0.10	0.2	<0.1	NT	0.039	0.008	7.59	1326	204
KG08	30/05/2013	107.0	38.0	294.0	5.5	296	516	43	<0.10	0.2	0.31	NT	0.180	0.018	7.09	1391	214
KG08	20/06/2017	111.3	41.1	250.8	5.2	256	498	71	<0.05	0.9	NT	<0.05	0.432	0.018	7.72	1256	212
KG08	01/11/2017	119.5	40.3	245.0	3.9	252	468	72	<0.10	0.4	NT	<0.05	0.407	0.018	8.14	1256	209
KG08	10/04/2018	102.7	37.5	239.3	5.7	273	432	85	<0.10	<0.3	NT	0.07	0.407	0.019	6.77	1299	180
KG08	17/10/2018	118.2	42.1	242.8	3.8	245	473	71	<0.05	<0.3	NT	<0.05	0.397	0.018	7.10	1144	206

Borehole No.	Date	Ca	Mg	Na	K	Alkalinity as $CaCO_3$	Cl	SO_4	NO_3 as N	F	NH_4 as N	PO_4 as P	Fe	Mn	pH**	TDS	EC
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	pH units	mg/ℓ	mS/m
KG08	16/10/2019	105.8	36.6	198.2	5.1	271	466	71	0.09	0.3	NT	<0.02	0.442	0.018	7.56	1263	191
Median		**98.5**	**31.8**	**163.1**	**5.1**	**240**	**330**	**61**	**0.80**	**0.3**	**0.31**	**0.13**	**0.235**	**0.018**	**7.58**	**949**	**156**
Minimum		**73.0**	**13.8**	**84.0**	**2.7**	**200**	**148**	**38**	**0.09**	**0.2**	**0.10**	**0.04**	**0.008**	**0.001**	**6.00**	**597**	**93**
Maximum		**119.5**	**55.0**	**335.0**	**13.8**	**296**	**598**	**85**	**3.20**	**0.9**	**0.39**	**0.23**	**0.442**	**0.140**	**8.14**	**1671**	**257**

NT = Not tested.

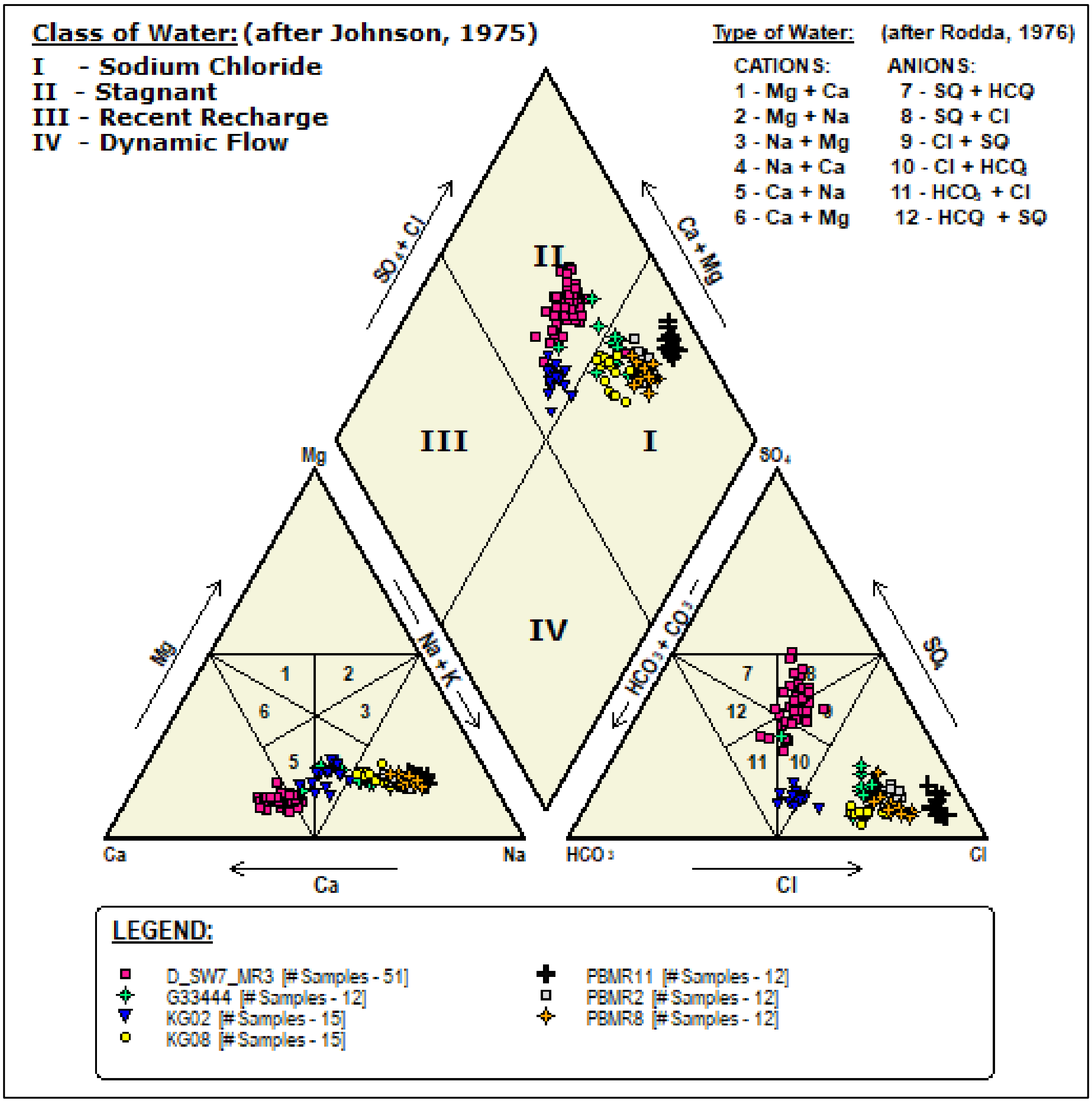


Figure 5.11.15
Piper Diagram for Water Samples from the Sandveld Aquifer

Selected radionuclide analyses of water samples from SSR boreholes were conducted in order to determine baseline levels. The results of these analyses are presented in ***Table 5.11.18*** and ***Table 5.11.19***. The gross β activity in the May 2008 sampling round is higher than in the November 2008 monitoring round. Neither K nor Ra-223 are present in high enough concentrations in either of the samples to account for the higher β activity in the May 2008 monitoring round, and this is considered to be due to the inherent uncertainties in this analytical method (Necsa analytical report explanation – see ***Appendix 5.11.G***).

Table 5.11.18
Radionuclide Analyses 2008: Sandveld Aquifer

Borehole No.	U-238			U-234			U-235			Th-230			Th-227		
	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
May 2008 Monitoring															
SRK-KG2	19.8	4.6	8.3	33.2	5.5	2.4	0.910	0.211	0.38	85	19	96	47.2	12.4	23.0
SRK-KG8	13.0	4.1	9.3	19.4	4.5	2.7	0.599	0.190	0.43	152	27	59	28.8	6.9	9.7
SRK-KG8 (duplicate)	8.2	6.1	20	32.4	10.3	20	0.380	0.280	0.94	313	55	120	34.9	15.1	28.0
November 2008 Monitoring															
SRK-KG2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SRK-KG8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SRK-KG8 (duplicate)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample	**Th-228**			**Ra-226**			**Ra-223**			**Gross α activity**			**Gross β activity**		
Id	**mBq/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**
May 2008 Monitoring															
SRK-KG2	53.3	11.1	16	22.9	2.5	3.5	0.56	2.5	3.5	-250	340	1 200	1 520	240	760
SRK-KG8	16.9	5.0	9.6	25.7	2.9	2.4	24.70	2.9	2.4	-350	450	1 500	2 080	250	780
SRK-KG8 (duplicate)	63.9	13.3	19	27.1	2.8	3.6	27.10	2.8	3.6	-150	470	1 600	1 590	250	780
November 2008 Monitoring															
SRK-KG2	NA	NA	NA	8.4	1.93	1.2	-0.39	1.4	3.8	-120	110	160	819	236	150
SRK-KG8	NA	NA	NA	25.2	3.50	1.3	53.40	6.8	9.5	-300	140	210	927	243	150
SRK-KG8 (duplicate)	NA	NA	NA	22.0	3.20	1.2	12.10	3.9	1.9	-240	130	190	677	238	150

MDA = minimum detectable activity concentration (@ 95% confidence level) NA = Not analysed. 1θ = reported uncertainty from counting statistics

Table 5.11.19
Radionuclide Analyses 2011 to 2020: Sandveld Aquifer

Borehole No.	Date	226Ra			223Ra			224Ra			Gross α activity			Gross β activity		
		mBq/ℓ	Unc.	MDA	mBq/ℓ	Unc.	MDA	mBq/ℓ	Unc.	MDA	mBq/ℓ	Unc.	MDA	mBq/ℓ	Unc.	MDA
SRK-KG2	01-May-11	19.90	7.00	6.70	11.40	7.60	9.10	<MDA		14.00	-220	57	230	150	170	580
SRK-KG2	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-390	700	2200	4130	460	1400
SRK-KG2	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-360	190	640	430	290	960
SRK-KG2	24-Jul-17	6.05	1.55	2.60	1.26	0.96	1.20	9.50	3.49	7.70	11	61	210	80	120	400
SRK-KG2	02-Nov-17	6.05	1.55	2.60	1.26	0.96	1.20	9.50	3.49	7.70	31	40	140	360	77	230
SRK-KG2	11-Apr-18	6.93	1.67	3.40	1.30	1.60	4.70	6.60	2.60	7.10	97	46	140	318	76	230
SRK-KG2	16-Oct-18	7.84	1.80	1.10	1.10	1.00	1.20	1.40	1.40	3.70	30	39	140	384	78	230
SRK-KG2	16-Oct-19	9.65	1.73	0.84	0.55	1.30	1.10	<MDA		1.80	62	30	93	308	67	200
SRK-KG8	01-May-11	39.30	3.50	0.86	2.11	1.72	0.96	<MDA		2.70	-280	99	390	47	180	590
SRK-KG8	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-390	900	3100	768	443	1400
SRK-KG8	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-410	270	920	420	300	980
SRK-KG8	20-Jul-17	33.40	3.20	0.84	2.00	1.70	2.50	4.63	2.07	2.50	-19	96	340	230	130	410
SRK-KG8	01-Nov-17	33.40	3.20	0.84	2.00	1.70	2.50	4.63	2.07	2.50	-10	57	220	170	72	230
SRK-KG8	10-Apr-18	32.00	3.70	5.60	-1.40	2.80	5.30	-0.08	2.20	9.30	42	59	210	321	76	230
SRK-KG8	16-Oct-18	40.20	4.00	1.10	1.61	1.80	1.20	5.19	2.60	3.50	-38	55	220	381	78	230
SRK-KG8	16-Oct-19	35.00	4.20	1.40	3.37	3.25	1.80	6.55	2.67	3.00	-32	40	170	-300	89	320
Minimum		**6.05**	**1.55**	**0.84**	**-1.40**	**0.96**	**0.96**	**-0.08**	**1.40**	**1.80**	**-410**	**30**	**93**	**-300**	**67**	**200**
Maximum		**40.20**	**7.00**	**6.70**	**11.40**	**7.60**	**9.10**	**9.50**	**3.49**	**14.00**	**97**	**900**	**3100**	**4130**	**460**	**1400**
Median		**25.95**	**3.20**	**1.25**	**1.46**	**1.70**	**1.50**	**5.19**	**2.60**	**3.60**	**-26**	**58**	**220**	**320**	**105**	**360**

MDA = minimum detectable activity concentration (@ 95% confidence level)   NA = Not analysed.   1θ = reported uncertainty from counting statistics

Stable Isotopes and tritium

Two water samples taken during the early SSR monitoring programme were submitted for D/H, O-18/O-16 and H-3 analysis and the results are presented in ***Table 5.11.20***. The SSR samples in ***Figure 5.11.16*** plot on the GMWL. This trend indicates normal precipitation and recharge processes at the site and surrounding area.

The data shown in ***Table 5.11.20*** indicate H-3 values between 0.2 to 2.1 TU for groundwater samples. The detectable levels of H-3 in the groundwater indicate a component of relatively recent recharge, as is to be expected in this shallow, unconfined aquifer. Sample SRK-KG8 shows recent recharge in the May 2008 monitoring but low (0.2 to 0.3 TU) in subsequent monitoring runs indicating primarily pre-1952 groundwater in this Sandveld Aquifer sample. The presence of the KNPS on site must also be taken into consideration as low-level emission of H-3 is normal from operational nuclear reactors.

Table 5.11.20
Stable Isotope and Tritium Analyses: Sandveld Aquifer

Borehole ID	Aquifer	δ D (‰)*	δ O-18 (‰)	Tritium (TU)	
May 2008 Monitoring					
SRK-KG2	Primary	-18.4	-3.61	2.1	±0.3
SRK-KG8	Primary	-18.3	-3.60	1.0	±0.2
SRK-KG8 (duplicate)	Primary	-18.2	-3.63	1.0	±0.2
November 2008 Monitoring					
SRK-KG2	Primary	-14.5	-3.11	2.0	±0.3
SRK-KG8	Primary	-19.2	-3.71	0.3	±0.2
SRK-KG8(duplicate)	Primary	-19.2	-3.71	0.2	±0.2
May 2009 Monitoring					
SRK-KG2	Primary	NA	NA	2.0	±0.3
SRK-KG8	Primary	NA	NA	0.2	±0.2
SRK-KG8(duplicate)	Primary	NA	NA	0.3	±0.2
May 2011 Monitoring					
SRK-KG2	Primary	NA	NA	1.3	±0.3
SRK-KG8	Primary	NA	NA	1.1	±0.3
SRK-KG8(duplicate)	Primary	NA	NA	0.9	±0.2

NA = Not analysed.
*delta O-18, the ratio of O-18 to O-16, in parts per thousand

Table 5.11.21
Tritium Analyses: Selected Boreholes, Sandveld Aquifer

Borehole No.	Date	TU	Uncertainty
SRK-KG2	23/11/2011	0.3	±0.2
SRK-KG2	23/05/2012	0.7	±0.2
SRK-KG2	21/11/2012	0.8	±0.2
SRK-KG2	30/05/2013	1.5	±0.3
SRK-KG2	10/04/2014	1.7	±0.3
SRK-KG2	15/10/2014	0.8	±0.3
SRK-KG2	24/07/2017	1.1	±0.3
SRK-KG2	02/11/2017	1.5	±0.3
SRK-KG2	11/04/2018	1.7	±0.3
SRK-KG2	16/10/2018	0.8	±0.2
SRK-KG2	16/10/2019	1.4	±0.3
SRK-KG2	20/05/2020	0.7	±0.3
SRK-KG2	19/10/2020	0.7	±0.2
Minimum		**0.3**	
Maximum		**1.7**	
Median		**0.8**	

Borehole No.	Date	TU	Uncertainty
SRK-KG8	23/11/2011	0.7	±0.2
SRK-KG8	23/05/2012	0.5	±0.2
SRK-KG8	21/11/2012	0.0	±0.2
SRK-KG8	30/05/2013	1.1	±0.3
SRK-KG8	09/04/2014	0.5	±0.2
SRK-KG8	15/10/2014	0.5	±0.2
SRK-KG8	20/07/2017	0.6	±0.2
SRK-KG8	01/11/2017	<0.2	±0.2
SRK-KG8	10/04/2018	0.5	±0.2
SRK-KG8	16/10/2018	0.5	±0.2
SRK-KG8	16/10/2019	1.6	±0.3
SRK-KG8	20/05/2020	0.8	±0.3
SRK-KG8	19/10/2020	0.3	±0.2
Minimum		**0.0**	
Maximum		**1.6**	
Median		**0.5**	

Tritium levels of <3 TU are the 'norm' at the KNPS site, but elevated levels of 4.8, 5.5 and 42 TU have been recorded in three boreholes within 50 m of the plant buildings (Eskom, 2002). These levels are probably the result of releases of tritiated steam and condensate and the pathways are as per the original design of the plant and are not due to uncontrolled releases or leaks.

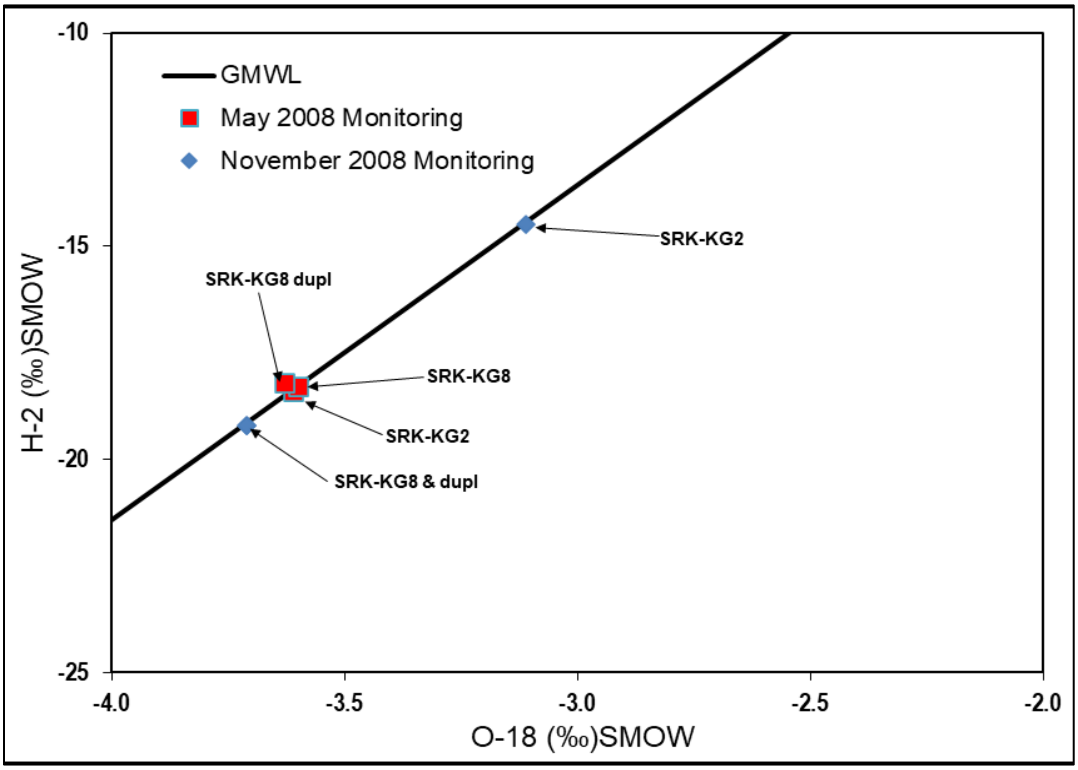


Figure 5.11.16
$\delta^{18}O$ versus δD: Hydrocensus Samples: Sandveld Aquifer

Adsorption testing

The adsorption of contaminants on the solid phases of the soil and aquifer materials is a critical aspect in evaluating the fate and transport of contaminants in the natural environment. The partition coefficient (K_d) provides an estimate of the potential for the adsorption of dissolved contaminants onto the solid phases. The K_d is defined as the ratio of the contaminant concentration associated with the solid to the contaminant concentration in the surrounding aqueous solution when the system is at equilibrium.

Two samples representing primary Sandveld Aquifer material underlying the site were submitted for adsorption testing. Sample KG-Comp 1 (0 to 1 m) represented a composite of sand from the SSR drilled boreholes and KG-Comp 2 (13 to 14 m) represented a composite of the Sandveld pebbles/shells. The samples were submitted to Necsa for the determination of the K_d of selected radionuclides/elements (Cs-137, Co-60, Sr-90 and U), selected partly on the basis of Koeberg-type reactor liquid releases (Eskom, 2002).

The method followed is that described by the Japanese Atomic Energy Research Institute (Yamaguchi & Nakayama, 2003). The K_d values determined for the site samples are summarised in ***Table 5.11.22*** and the Necsa analytical report is given in ***Appendix 5.11.I***.

Table 5.11.22
Partition Coefficients for Selected Radionuclides at Different pH Values

Isotope/ Element	Sample ID	K_d (mℓ/g)		
		pH 3	pH 7	pH 12
Cs-137	KG-Comp 1 (0-1 m bgl)	5.59	7.32	5.36
	KG-Comp 2 (13-14 m bgl)	2.86	3.25	2.87
Co-60	KG-Comp 1 (0-1 m bgl)	6.48	3 760	29.30
	KG-Comp 2 (13-14 m bgl)	11.20	4 010	58.20
Sr-90	KG-Comp 1 (0-1 m bgl)	969×10^{-1}	4.24	7.22
	KG-Comp 2 (13-14 m bgl)	706×10^{-1}	1.18	3.11
U	KG-Comp 1 (0-1 m bgl)	1.59	442	173
	KG-Comp 2 (13-14 m bgl)	6.20	668	460

Low K_d values were measured for the Cs-137 tracer species for both samples with relatively small differences in K_d at the different pH values. The K_d values for Co-60 show large differences at different pH values. The measured values at pH 3 were low, moderate at pH 12 and high at pH 7. Low K_d values were measured for the Sr-90 tracer species for both the samples with small differences in K_d values at pH 7 and 12 but lower at pH 3. Relatively high K_d values for the different uranium tracer species were measured at pH 7 and 12 for both samples. At a pH of 3, the measured K_d values were low.

Given the natural pH of the site groundwater ranging from 6.7 to 8.0, the retardation of Cs-137 and Sr-90 in the calcareous sandy aquifer is expected to be low. The rate of migration of both Co-60 and dissolved U species are likely to be moderately retarded relative to that of conservative species (H-3). The Sr-90 K_d value was used in the scenario modelling.

5.11.6.2 Aquifer 2: Fractured-rock Malmesbury Aquifer

The Malmesbury Aquifer at the site is formed by sediments of the Tygerberg Formation which consists mainly of alternating greyish fine to medium grained greywacke and phyllitic shale. They have been metamorphosed to hornfels in places by proximity to intrusions of the Cape Granite Suite. These rocks weather to produce varying thicknesses of yellow and/or grey clay and underlie the entire study area forming a semi-impervious base to the Atlantis Aquifer and a semi-confining layer to the Malmesbury Aquifer. This is termed the Malmesbury Aquitard. The Malmesbury Aquifer and Aquitard have not been studied to the same degree as the Atlantis Aquifer by past researchers, as the Malmesbury Group has previously been taken to form an impermeable base to the former e.g. (Council for Scientific and Industrial Research, 2017).

The degree and depth of weathering varies considerably across the site. Unweathered greywacke is present within 6 m of the bedrock surface, while weathering of the mudstone or shale extends to 26 m in some places.

Hydraulic Properties

The hydraulic properties of the Malmesbury Aquifer were determined from analysis of pumping and packer tests. The fractured rock aquifer is highly anisotropic and aquifer parameters vary significantly across the site. Work done at the planned PBMR DPP site indicated a T value of 30 m^2/d (Council for Scientific and Industrial Research, 2000), probably representing 'fracture' T. Test pumping analysis for the SSR boreholes indicate T values ranging fairly widely from 5 to 180 m^2/d for this aquifer, which is to be expected in an anisotropic, fractured aquifer.

Packer test results for SSR boreholes indicate K values ranging from 0.1 to 6.0 m/d in the upper 20 m of the formation, which is the likely zone of influence on nuclear installation foundations, i.e. water levels, hydrostatic pressure and inflows.

Storativity values determined for SSR boreholes range from 0.0001 to 0.0029, which are generally taken to indicate confined to semi-confined conditions. These values compare well with those obtained by other investigations (Eskom, 2006), (Council for Scientific and Industrial Research, 2000), (Africon, 2000) and (SRK Consulting, 2007), and fit with the aquifer/geological profile of fractures with a probably semi-confining weathered Malmesbury Group layer.

A summary of the hydraulic parameters is presented in ***Table 5.11.23***. Hydraulic parameters for the Malmesbury Aquitard were derived (approximated) from the numerical modelling calibration and are indicated in ***Table T-5.11.24*** and described in ***Subsection 5.11.7***.

Borehole Yields

Boreholes drilled into the Malmesbury Aquifer typically show considerably lower yields than primary aquifer boreholes, i.e. <2 ℓ/s. This is illustrated by an assessment of the Malmesbury Aquifer during 2000 to 2001 (SRK Consulting, 2010) and (SRK Consulting and Freshwater Consulting Group, 2011). Exploration boreholes drilled in the shale at the candidate CCT regional landfill site south of Atlantis yielded between 0.1 and 0.3 ℓ/s (Parsons and Associates, 2006), although the purpose of this drilling programme was site characterisation/monitoring, not to establish high yielding production boreholes. During exploratory drilling for the PBMR DPP, a fracture with a blow yield of 12 ℓ/s was encountered in borehole P-01 (Murray, 2000). This borehole was test pumped at 10.4 ℓ/s but this yield was predicted to drop with time as the fracture became dewatered.

During this SSR work, the Malmesbury Aquifer was intersected below the Sandveld Group at depths varying from 14 to 25 m bgl. This aquifer is highly fractured with water-bearing fractures encountered at depths from 18 to 58 m bgl. The fractures are moderate to high yielding with airlift yields ranging from 2 to 12 ℓ/s. Sustainable yields of 0.3 to 6.0 ℓ/s have been calculated for these boreholes (***Table 5.11.23***). A sustainable yield of *c*.15 ℓ/s is obtainable from the highest yielding boreholes.

Based on these results, the Malmesbury Aquifer at the site could provide an additional source of groundwater supply, e.g. for site establishment activities. However, sustained pumping at high rates along/near to the coast will be constrained due to the potential for saline water intrusion.

Groundwater Levels

Groundwater levels measured in boreholes drilled into the Malmesbury Aquifer are shown in ***Table 5.11.24***. These water levels were measured after drilling (March 2008) and during bi-annual monitoring from May 2008 to July 2020. A data logger, recording hourly water level and temperature, installed in borehole SRK-KG3 in June 2008, indicates maximum variation of 1.47 m in groundwater level over 12 years of monitoring (***Figure 5.11.17***). Seasonal wet-dry water level variation, however, is on average *c*.0.5 m. Depth to groundwater varies between 0.70 and 5.46 m bgl with an average maximum variation of 1.30 m between the highest and lowest levels recorded. Depth to groundwater at the illustrative new nuclear installation footprint, measured at boreholes SRK-KG1, -KG3, -KG4 and -KG6, varies between 0.70 and 3.36 m bgl with a maximum variation of 1.31 m between the highest and lowest levels. This fluctuation is considered to be due to a combination of the buffering effect of the overlying Sandveld Aquifer (leakage/hydraulic connection between the two aquifers), lack of direct recharge, lack of abstraction and 'regulation' of water levels by outflows in the coastal strip discharge area.

A hydrograph of the groundwater level monitored by means of the continuous data logger in SRK-KG3 is shown in ***Figure 5.11.18***. The graph shows groundwater levels from June 2008 until July 2020 and rainfall measured at the on-site meteorological station. The graph shows a variation of groundwater level with rainfall, with an increase in water level in winter/spring after the onset of the main rainfall period and a decrease in water level during drier periods (summer). Overall, the water level has varied by *c*.1.3 m between the wettest and driest seasons, whilst the average seasonal variation is *c*.0.5 m.

Table 5.11.23
Summary of Fractured Malmesbury Aquifer Parameters

SSR Borehole No.	Transmissivity T (m^2/d)	Storativity S	Aquifer Thickness D (m)	Calculated Hydraulic Conductivity K (m/day)	Assumed Porosity %	Max Test Yield (ℓ/s)	Recommended Sustainable Yield (ℓ/s)	Aquifer Type	Comments
SRK-KG1	19	0.0001	56	0.3	0.5	15.00	1.00	Fractured	Sustainable yield estimated from Calibration Graph. T & S determined by using the FC-Non-Linear Method
SRK-KG3	5	0.0009	53	0.1	0.5	4.50	0.30	Matrix	
SRK-KG4	70	0.0014	42	1.7	0.5	15.00	6.00	Fractured	Sustainable yield calculated with FC, Cooper-Jacob & Theis methods
SRK-KG4				37.7				Fractured	Packer test
SRK-KG6	31	0.0019	37	0.8	0.5	10.25	2.40	Fractured	Sustainable yield calculated with FC, Cooper-Jacob & Theis methods
SRK-KG7	113	0.0003	37	3.1	0.5	14.00	4.50	Fractured	Sustainable yield estimated from Calibration Graph. T & S determined by using the FC-Non-Linear Method
SRK-KG9	180	0.0029	30	6.0	0.5	5.10	4.00	Fractured	
SRK-KG11				0.2				Matrix	Packer test
Average	**70**	**0.0012**	**43**	**6.2**		**10.64**	**3.03**		
Median		**50**	**0.0011**	**40**	**1.3**		**12.13**	**3.20**	

Note: K was calculated by dividing transmissivity by aquifer thickness. Aquifer thickness = Deepest water strike minus the rest water level.

Table 5.11.24
Groundwater Levels for SSR Monitoring Boreholes (Malmesbury Aquifer)

Borehole No.	Depth (m)	Surface Elevation (m amsl)	Minimum Water Level Depth (m bgl)	Maximum Water Level Depth (m bgl)	Average Water Level Depth (m bgl)	Water Level Depth Variation (m)
SRK-KG1	60.97	9.24	2.08	3.36	2.78	1.28
SRK-KG3#	56.14	8.59	1.14	2.68	1.91	1.53
SRK-KG4	59.97	12.98	0.70	2.19	1.48	1.49
SRK-KG6	42.07	18.21	1.70	2.62	2.07	0.92
SRK-KG9	43.35	14.58	4.01	5.19	4.63	1.18
PBMR1	60.90	9.24	4.07	5.46	4.37	1.39
Ave Variation All						1.30
Ave Variation new nuclear installation footprint						1.31

Values derived from monitoring data collected from March 2008 to May 2020
Automatic data logger in this borehole – hourly data from June 2008 to July 2020
Boreholes SRK-KG01, -03, -04 and -06 on or close to the Illustrative new nuclear installation footprint

Distinct high rainfall events in August 2008, December 2009, June 2013 and August 2013 show individual peaks in water level rise indicating high rainfall events will affect water levels on site. However, this rise is postulated to be due to a hydrostatic pressure effect on the semi-confined Malmesbury Aquifer due to recharge on areas of exposed Malmesbury rocks inland to the east rather than direct recharge in the site area, where this aquifer is not exposed. A one-day rainfall of 35 mm on 9 June 2008 resulted in a 0.40 m rise in the piezometric level over approximately 10 days (***Figure 5.11.18***). The effects of lower rainfall in 2009, 2010, 2011 and 2012 compared to 2008 and 2013 can be seen in the lower peak water level for 2009 to 2012. The low rainfall (severe drought according to the SPI method) of 2017 & 2018 resulted in the lowest water level of the 12-year monitoring period.

Water level data obtained from adjacent SSR monitoring boreholes during the test pumping of SRK-KG4 and SRK-KG6 indicate connectivity between the boreholes located in an east-west direction (SRK-KG3) and a north-south direction (SRK-KG7). This can probably be attributed to the dominant fault trends of northwest, east and northeast, as previously described. Drawdown of between 0.4 m (SRK-KG3) to 3.5 m (SRK-KG7) was observed over distances of 115 m and 31 m, respectively, during the test pumping programme.

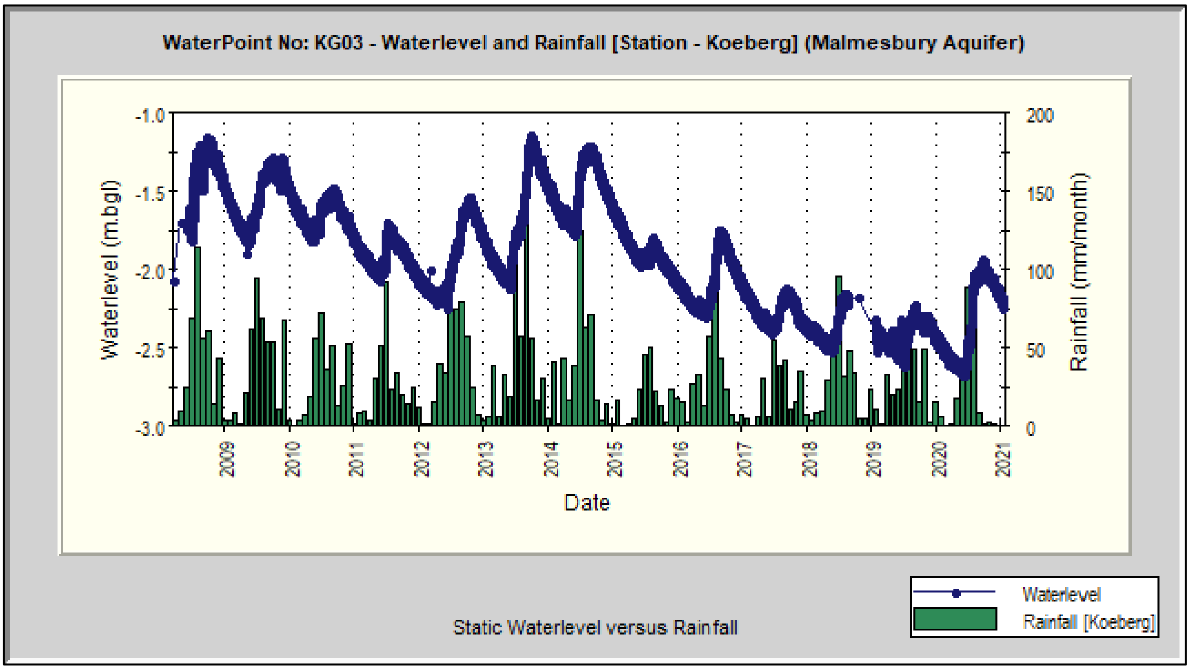


Figure 5.11.17
Hydrograph: SRK-KG3 (Malmesbury Aquifer)

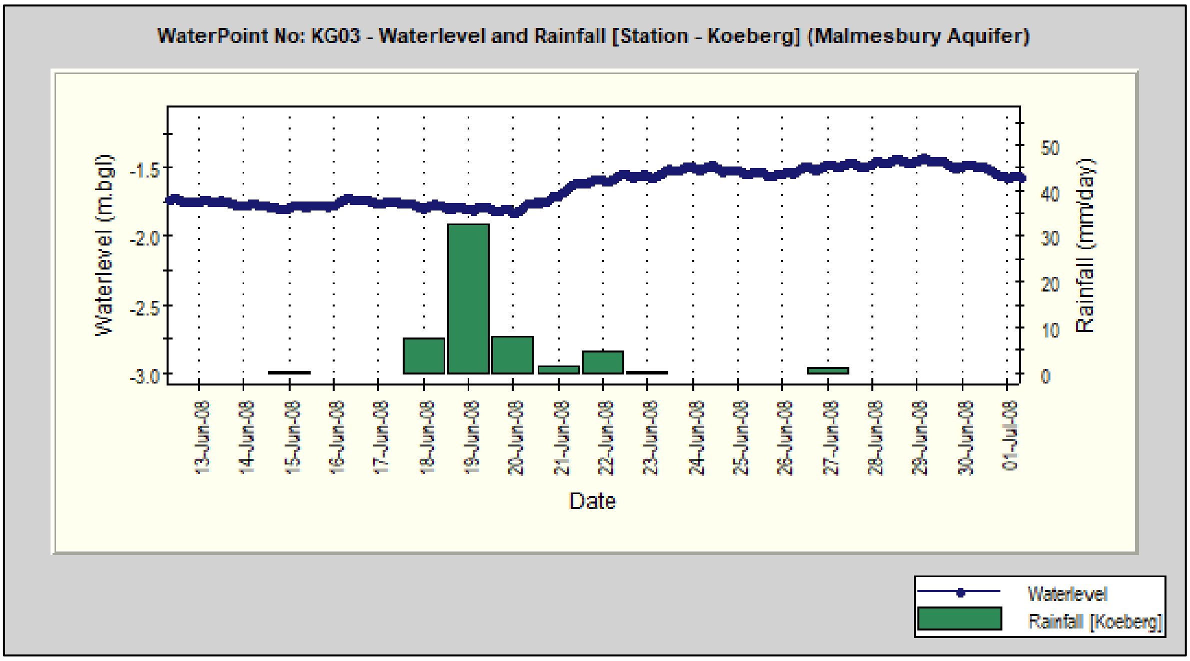


Figure 5.11.18
Hydrograph: SRK-KG3 Daily Rainfall versus Water Level from 13-Jun-08 to 1-Jul-08 (Malmesbury Aquifer)

During yield testing (72 h constant discharge) of SRK-KG4, a water level drawdown of 0.93 m was observed in observation borehole SRK-KG5, which is 94 m to the east and was drilled into the overlying Sandveld Aquifer. This is further indication that there is interconnection between the upper Sandveld Aquifer and lower Malmesbury Aquifer.

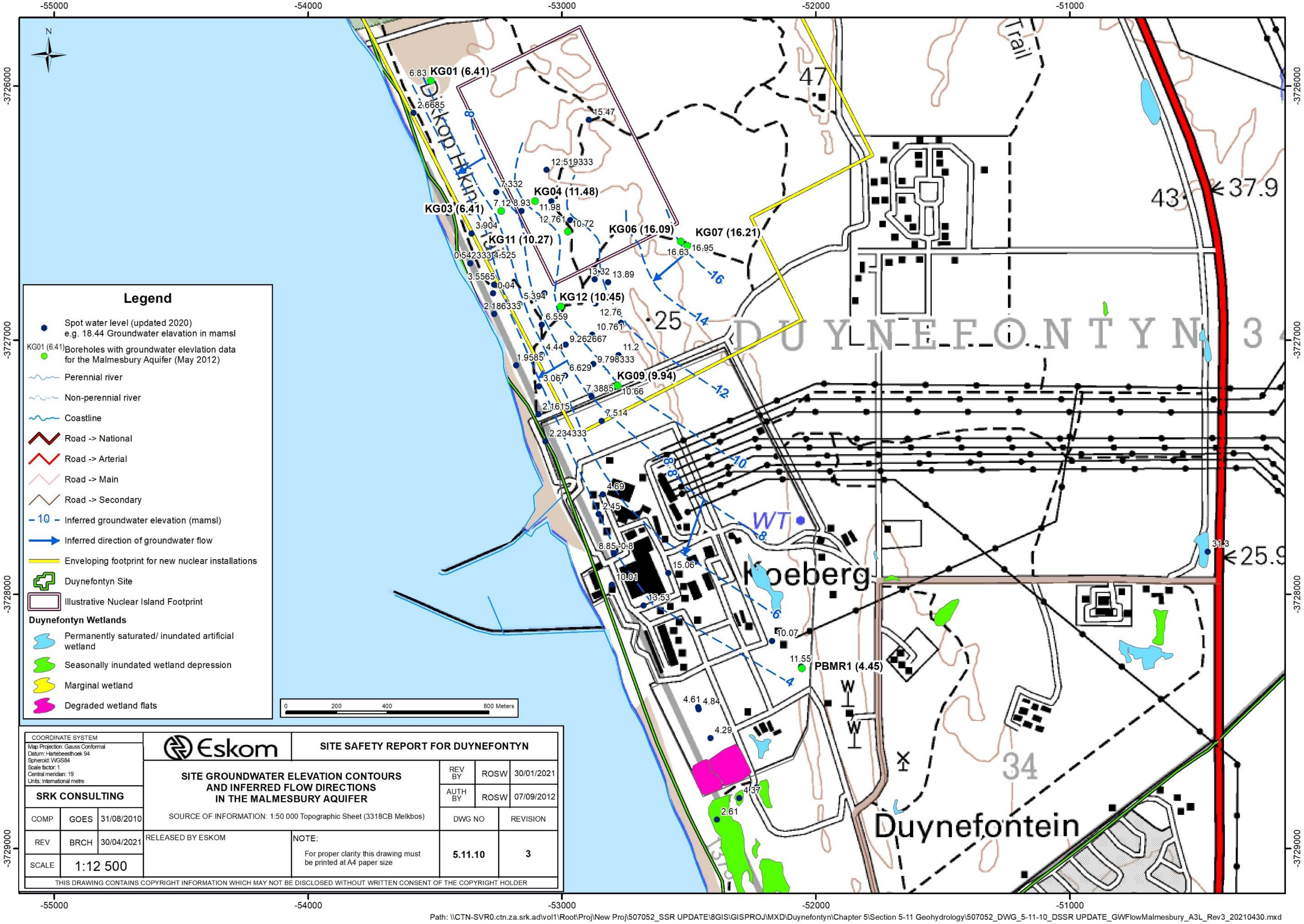
Groundwater levels and interpolated elevation contours (m amsl) for the site are shown in ***Drawing 5.11.10***. The contours indicate that the main groundwater flow direction is in a southwesterly to westerly direction, i.e. towards the coast.

Groundwater Quality

Down-hole EC and pH profiling of the SSR boreholes during test pumping indicates that EC ranges from 198 to 275 mS/m and pH from 7.9 to 8.9. The EC generally increases with depth with sudden but relatively small increases at some of the water strikes as shown in ***Figure 5.11.19***. The pH decreases with depth.

A summary of chemical analyses of groundwater taken from the Malmesbury Aquifer boreholes from May 2008 to May 2020 is given in ***Table*** 5.11.25.

The table shows fairly homogeneous chemistry within the Malmesbury Aquifer. Electrical conductivity ranges from 203 to 358 mS/m (median is 212 mS/m) and pH from acidic (5.6) to alkaline (8.14) with a median of 7.2. Electrical conductivity at the illustrative footprint ranges from 203 to 358 mS/m (median is 238 mS/m) and pH from acidic (5.6) to alkaline (8.4) with a median of 7.3. Piper plots of water samples taken from selected SSR boreholes are shown in ***Figure 5.11.20***. The results show a dominant NaCl character for groundwater from the Malmesbury Aquifer.



Legend
Spot water level (updated 2020) e.g. 18.44 Groundwater elevation in mamsl
Boreholes with groundwater elevlation data for the Malmesbury Aquifer (May 2012)
Perennial river
Non-perennial river
Coastline
Road -> National
Road -> Arterial
Road -> Main
Road -> Secondary
Inferred groundwater elevation (mamsl)
Inferred direction of groundwater flow
Enveloping footprint for new nuclear installations
Duynefontyn Site
Illustrative Nuclear Island Footprint
Duynefontyn Wetlands
Permanently saturated/ inundated artificial wetland
Seasonally inundated wetland depression
Marginal wetland
Degraded wetland flats
KG01 (6.41)
KG03 (6.41)
KG04 (11.48)
KG06 (16.09)
KG07 (16.21)
KG11 (10.27)
KG12 (10.45)
KG09 (9.94)
PBMR1 (4.45)
Koeberg
Duynefontein
DUYNEFONTYN
WT
COORDINATE SYSTEM
Map Projection: Gauss Conformal
Datum: Hartebeesthoek 94
Spheroid: WGS84
Scale factor: 1
Central meridian: 19
Units: International metre
SRK CONSULTING
Eskom
SITE SAFETY REPORT FOR DUYNEFONTYN
SITE GROUNDWATER ELEVATION CONTOURS AND INFERRED FLOW DIRECTIONS IN THE MALMESBURY AQUIFER
SOURCE OF INFORMATION: 1:50 000 Topographic Sheet (3318CB Melkbos)
REV BY ROSW 30/01/2021
AUTH BY ROSW 07/09/2012
COMP GOES 31/08/2010
REV BRCH 30/04/2021
SCALE 1:12 500
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NOTE: For proper clarity this drawing must be printed at A4 paper size
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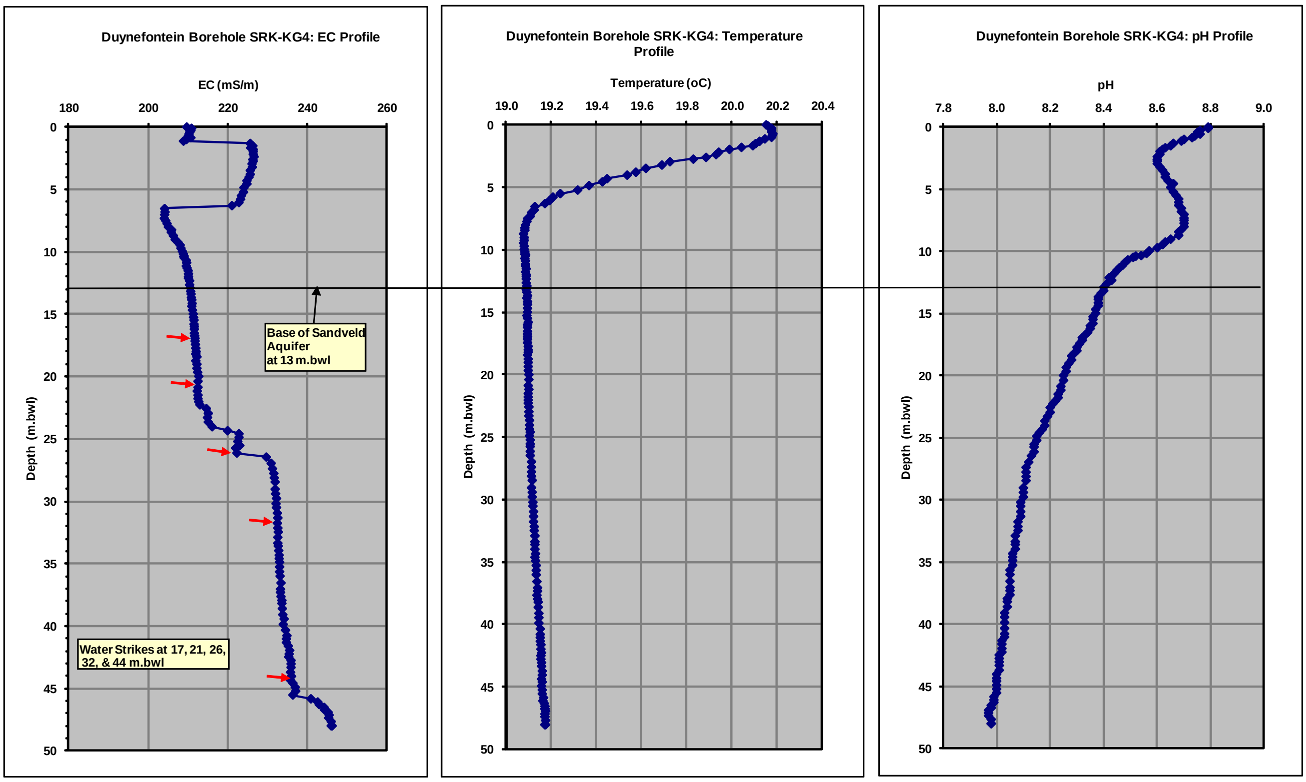


Figure 5.11.19
EC, Temperature & pH Profiles: SRK-KG4 (Malmesbury Aquifer)

Radionuclide analyses of water samples from SSR boreholes were conducted in order to determine baseline levels, as described under ***Subsection 5.11.6.5***. The results of these analyses are presented in ***Table*** 5.11.26. Sample SRK KG4 shows slightly elevated β activity in the May 2008 monitoring round, but lower values in the June 2008 round. These are for background information purposes and do not affect the safety assessment of the site.

Langelier Saturation indices vary from -1 to 0.46 indicating that the groundwater will cause mild scaling. Sulfate concentrations are between 1.8 and 77 mg/ℓ, indicating minimal corrosion potential to foundations. The Larson-Skold indices for mild steel for groundwater sampled from boreholes in the Malmesbury Aquifer range from 3.6 to 144.8, with a median of 5.1, which indicates that a tendency towards high corrosion rates of a local type should be expected. Given these indices and the coastal environment, use of corrosion resistant materials must be considered in the nuclear installation design.

Table 5.11.25
Chemical Analyses: Malmesbury Aquifer

Borehole No.	Date Sampled	Ca	Mg	Na	K	Alkalinity (as $CaCO_3$)	Cl	SO_4	NO_3 (N)	F	NH_4 (as N)	PO_4 (as P)	Fe	Mn	pH	EC (mS/m)
SRK-KG01	20-May-08	183	48	421	6.1	216	1 007	21	5.4	0.1	<0.10	1.50	<0.001	0.080	7.4	357
	03-Nov-08	119	43	448	9.3	68	1 025	1.8	4.5	0.1	<0.10	1.50	6.500	0.007	7.0	349
	04-May-09	114	64	502	9.3	28	1 279	4.8	7.1	0.1	<0.10	0.24	1.900	0.060	6.5	328
	27-May-11	99	40	621	13.8	10	1 024	<3	<0.1	NA	0.38	NA	<0.100	0.180	6.5	336
	28-Nov-11	90	35	477	5.5	12	1 023	8.3	<0.1	0.6	0.23	<0.5	1.799	0.180	6.0	338
	23-May-12	122	40	485	7.6	3	991	<0.20	0.2	0.2	0.23	<0.10	<0.100	0.270	6.4	327
	26-Nov-12	110	40	446	6.0	7	1 003	<0.20	<0.1	0.1	0.23	<0.10	0.018	0.180	7.3	325
	30-May-13	105	39	433	5.3	3.3	952	0.4	<0.1	0.4	0.54	<0.10	1.600	0.218	5.9	328
	20-Jun-17	171	42	430	4.8	208	973	7.5	<0.05	0.70	NA	0.72	2.044	0.203	7.82	342
	01-Nov-17	180	42	426	3.0	177	960	3.0	<0.20	-0.30	NA	0.14	2.841	0.201	7.83	340
	11-Apr-18	153	38	418	5.6	216	876	1.9	<0.20	-0.30	NA	0.27	1.448	0.204	6.81	305
	17-Oct-18	182	43	428	2.9	218	1174	2.8	<0.05	0.50	NA	<0.06	0.021	0.197	7.30	334
	17-Oct-19	155	37	453	5.2	212	947	1.9	0.16	-0.30	NA	<0.02	1.046	0.199	7.73	362
	20-May-20	147	44	593	4.3	152	1331	1.2	<0.05	-0.30	NA	0.01	4.598	0.219	7.79	338
	20-Oct-20	168	44	441	4.7	212	900	2.2	<0.05	-0.30	NA	<0.01	0.862	0.205	7.93	347
SRK-KG04	20-May-08	114	33	284	4.5	233	603	73	2.5	0.2	<0.10	11.50	<0.001	0.170	7.8	248
	03-Nov-08	114	32	302	6.1	229	625	57	2.4	0.2	<0.10	2.10	0.850	0.020	7.9	257
	04-May-09	110	42	351	6.3	215	712	63	3	0.2	<0.10	0.29	1.000	0.120	7.9	236
	27-May-11	32	24	397	7.5	55	640	<3	0.1	<0.1	<0.10	NA	<0.100	0.100	7.4	203
	28-Nov-11	27	24	360	2.7	59	619	3.2	<0.1	0.4	<0.10	0.34	3.200	0.108	6.0	210
	23-May-12	114	27	341	5.1	232	576	64	0.3	0.2	<0.10	NA	<0.100	0.108	7.6	237

Borehole No.	Date Sampled	Ca	Mg	Na	K	Alkalinity (as $CaCO_3$)	Cl	SO_4	NO_3 (N)	F	NH_4 (as N)	PO_4 (as P)	Fe	Mn	pH	EC (mS/m)
	26-Nov-12	72	28	330	3.5	169	593	0.4	<0.1	0.1	<0.10	<0.10	0.079	0.100	8.1	217
	30-May-13	60	25	355	3.2	148	702	3	<0.1	0.5	0.46	<0.10	3.098	0.079	6.8	216
	20-Jun-17	107	28	327	3.0	221	609	57.5	0.75	0.80	NA	0.72	1.150	0.104	7.83	239
	02-Nov-17	114	28	321	1.9	212	572	60.2	<0.20	0.30	NA	<0.06	1.241	0.106	8.04	236
	10-Apr-18	100	26	316	3.4	244	526	56.5	<0.20	-0.30	NA	<0.06	0.895	0.109	6.78	215
	17-Oct-18	111	28	320	1.7	220	575	58.8	<0.05	-0.30	NA	<0.06	0.627	0.104	7.17	232
	17-Oct-19	102	25	321	3.0	235	560	60.8	<0.05	-0.30	NA	<0.02	0.654	0.100	7.72	241
	17-Oct-19	95	30	380	2.7	208	672	56.4	<0.05	-0.30	NA	0.01	3.554	0.131	7.95	233
	21-Oct-20	107	29	338	2.9	227	568	59.8	<0.05	-0.30	NA	0.05	0.529	0.122	7.98	245
SRK-KG06	20-May-08	111	30	273	4.0	204	586	56	2.2	0.2	<0.10	10.80	<0.001	0.150	7.5	234
	03-Nov-08	112	26	275	6.6	208	586	42	2	0.2	<0.10	1.50	10.000	0.020	8.1	238
	04-May-09	114	41	325	6.8	197	676	37	2.9	0.2	<0.10	0.40	5.000	0.170	7.5	233
	27-May-11	95	25	384	7.6	156	672	<3	<0.1	<0.1	0.23	NA	<0.100	0.100	7.4	210
	28-Nov-11	39	24	359	2.7	62	628	4.3	<0.1	<0.1	<0.10	0.55	8.199	0.200	5.6	212
	23-May-12	82	25	340	5.1	160	555	0.3	0.2	0.1	<0.10	<0.10	<0.100	0.090	7.9	218
	26-Nov-12	66	26	322	4.0	116	602	0.2	<0.1	0.2	<0.10	<0.10	0.018	0.128	7.8	215
	30-May-13	111	25	348	3.7	217	696	30	<0.1	<0.1	0.46	<0.10	0.008	0.170	7.5	229
	25-Jun-17	113	28	321	3.4	208	632	49.5	<0.05	0.80	NA	<0.06	4.350	0.163	7.95	241
	01-Nov-17	122	28	319	2.3	204	596	50.3	<0.20	<0.30	NA	<0.06	4.312	0.154	8.10	240
	10-Apr-18	105	26	313	3.8	218	551	47.8	<0.20	<0.30	NA	<0.06	3.969	0.161	6.90	214
	17-Oct-18	115	34	331	2.4	218	608	71.2	0.20	<0.30	NA	<0.06	0.396	0.019	7.14	244
	17-Oct-19	102	30	349	3.8	223	595	72.1	0.20	<0.30	NA	<0.02	1.166	0.111	7.74	258
	17-Oct-19	103	29	343	3.0	192	613	53.3	<0.05	<0.30	NA	0.02	0.832	0.142	7.91	237
	20-Oct-20	107	33	340	3.4	209	565	67.6	<0.05	<0.30	NA	0.02	0.659	0.119	7.88	250

Borehole No.	Date Sampled	Ca	Mg	Na	K	Alkalinity (as $CaCO_3$)	Cl	SO_4	NO_3 (N)	F	NH_4 (as N)	PO_4 (as P)	Fe	Mn	pH	EC (mS/m)
SRK-KG09	20-May-08	85	33	312	3.5	234	560	87	1.3	0.3	<0.10	7.50	0.070	0.130	7.5	232
	03-Nov-08	82	32	325	6.0	235	542	65	1.7	0.2	<0.10	1.80	1.000	0.010	7.0	236
	04-May-09	75	38	331	5.0	248	603	67	1.7	0.2	<0.10	0.94	0.790	0.130	6.5	209
	27-May-11	78	29	410	6.8	229	569	63	0.1	0.1	<0.10	NA	<0.100	0.119	7.5	216
	28-Nov-11	86	31	391	2.2	229	564	78	<0.1	0.4	<0.10	0.50	0.238	0.009	5.9	230
	23-May-12	90	30	351	4.9	245	515	79	0.2	0.2	<0.10	0.15	0.028	0.128	7.5	221
	26-Nov-12	83	29	371	3.4	239	523	276	0.1	<0.1	<0.10	0.15	0.018	0.003	8.0	221
	30-May-13	82	28	356	3.2	242	573	44	<0.1	0.1	0.23	<0.10	0.008	0.002	6.9	223
	25-Jun-17	89	32	334	2.9	232	585	65.2	0.75	0.8	NA	<0.06	0.288	0.067	7.86	233
	02-Nov-17	98	33	330	2.1	226	557	66.3	<0.20	0.3	NA	<0.06	0.226	0.088	8.07	234
	10-Apr-18	82	29	323	3.3	258	507	67.1	<0.20	<0.3	NA	0.12	-0.020	0.015	7.44	201
	17-Oct-18	99	34	333	1.9	223	582	65.6	<0.05	<0.3	NA	<0.06	0.479	0.126	7.06	235
	16-Oct-19	88	31	335	3.1	254	568	66.7	0.09	<0.3	NA	0.03	0.487	0.119	7.65	184
	16-Oct-19	83	34	361	2.6	224	575	66.6	0.07	<0.3	NA	0.09	0.026	0.054	7.97	236
	20-Oct-20	93	35	345	2.9	236	589	68.0	<0.05	<0.3	NA	0.09	0.540	0.130	7.81	247
Minimum		27	24	273	2	3	507	<3.0	<0.20	<0.3	<0.1	<0.06	-0.100	0.002	5.59	184
Maximum		183	64	621	14	258	1331	276.0	7.10	0.8	0.5	0.72	8.199	0.270	8.10	362
Median		104	31	347	4	216	603	51.8	<0.05	0.1	<0.1	<0.01	0.535	0.121	7.59	236

All values are in mg/ℓ, except for EC, which is in mS/m and pH, which has no unit. NA = Not analysed. < = Below detection limit

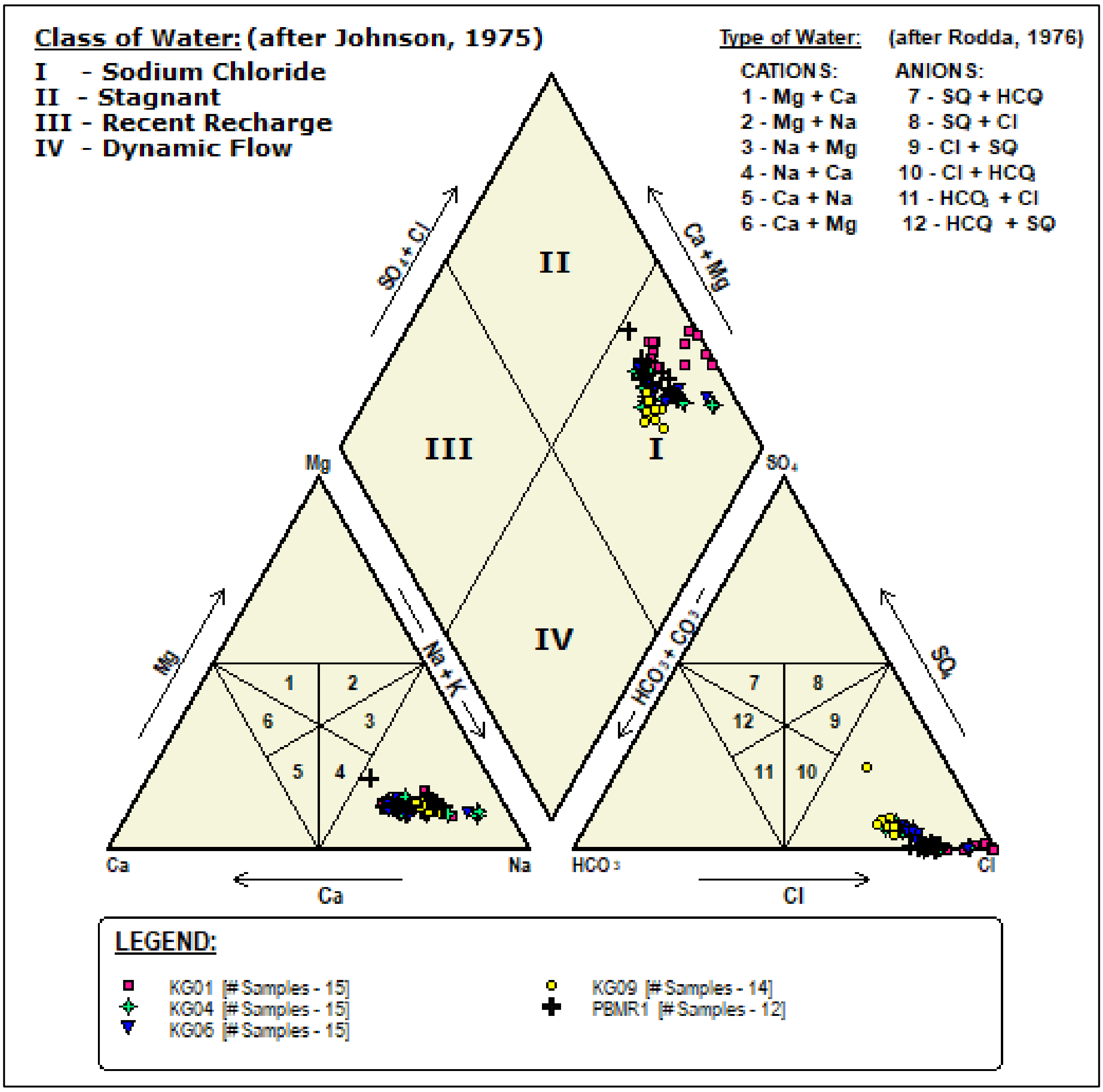


Figure 5.11.20
Piper Diagram for Water Samples from Monitoring Boreholes in the Malmesbury Aquifer

Table 5.11.26
Radionuclide Analyses: Malmesbury Aquifer 2008

Borehole No.	U-238			U-234			Th-230			Th-227			Th-228			Ra-226			Ra-223			Gross α activity			Gross β activity		
	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
May 2008 Monitoring																											
SRK-KG1	12.0	5.6	16.0	14.8	5.1	29.4	110.0	27.0	110	-4.3	8.5	26	56.5	16.4	31.0	253.0	11.0	5.1	-7.4	17.0	17	-140	570	1 900	1 160	250	790
SRK-KG4	4.1	2.5	7.5	29.4	5.9	9.5	141.0	26.0	73	29.3	7.6	12	9.7	4.6	12.0	83.0	6.3	3.4	15.0	10.0	270	-180	420	1 400	1 490	250	770
SRK-KG6	3.5	6.1	26.0	38.3	11.6	9.5	52.2	10.3	37	7.2	4.6	13	18.1	3.9	2.2	34.9	4.1	1.3	28.0	7.9	3.5	-240	420	1 400	600	240	770
SRK-KG9	12.0	7.2	22.0	29.0	10.3	22.0	95.0	17.5	48	21.3	6.0	12	10.6	3.7	7.8	75.7	6.2	5.1	-10.0	9.7	17	-190	430	1 500	1 750	250	770
November 2008 Monitoring																											
SRK-KG1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	19.4	3.0	1.9	19.4	3.5	5.7	-100	150	220	1 360	250	150
SRK-KG4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	92.3	6.1	4.3	6.6	4.5	2.1	-49	140	210	871	242	150
SRK-KG6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	44.6	4.6	5.3	14.8	5.2	6.8	-26	140	210	875	242	150
SRK-KG9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	78.5	6.3	1.4	15.9	6.7	6.0	-210	140	210	851	242	150

mBq/ℓ = milli Becquerel per litre MDA = Minimum Detectable Activity Concentration 1θ = 1 sigma = uncertainty calculated mainly from counting statistics NA = Not analysed

Table 5.11.27
Radionuclide Analyses: Malmesbury Aquifer Monitoring

Borehole	Sampling	U-238			U-234			Uranium			Ra-226			U-235		
No.	Date	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mg/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
PBMR1	01-May-11	7.7	2.1	1.5	15.6	3.0	1.5	0.9	0.0	1.5	33.2	3.3	3.8	0.4	0.1	0.1
	01-Nov-11	NA	NA	NA	NA	NA	NA	1.0	0.1	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.7	0.2	1.5	NA	NA	NA	NA	NA	NA
	25-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	87.8	5.6	3.3	NA	NA	NA
	31-Oct-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	87.8	5.6	3.3	NA	NA	NA
	09-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	102.0	6.0	4.0	NA	NA	NA
	15-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	86.9	6.9	1.5	NA	NA	NA
	15-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	84.5	5.2	0.9	NA	NA	NA
SRK-KG1	21-May-08	12.0	5.6	16.0	14.8	5.1	4.6	NA	NA	NA	253.0	11.0	5.1	0.6	0.3	0.7
	05-Nov-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	24.2	2.9	3.1	NA	NA	NA
	01-May-11	3.4	1.1	1.0	5.9	1.5	1.0	0.7	0.2	1.5	151.0	7.0	0.8	0.2	0.1	0.0
	01-Nov-11	NA	NA	NA	NA	NA	NA	2.3	0.2	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.4	0.1	1.5	NA	NA	NA	NA	NA	NA
	20-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	203.0	8.0	0.8	NA	NA	NA
	01-Nov-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	203.0	8.0	0.8	NA	NA	NA
	11-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	225.0	8.0	1.9	NA	NA	NA
	17-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	271.0	10.0	1.0	NA	NA	NA
	17-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	261.0	10.0	1.1	NA	NA	NA
SRK-KG2	21-May-08	19.8	4.6	8.3	33.2	5.5	2.4	NA	NA	NA	22.9	2.5	3.5	0.9	0.2	0.4
	05-Nov-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.4	1.9	1.2	NA	NA	NA
	01-May-11	12.6	2.0	0.9	17.7	2.5	0.9	0.9	0.3	1.5	19.9	7.0	6.7	0.6	0.1	0.0
	01-Nov-11	NA	NA	NA	NA	NA	NA	1.5	0.1	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.5	0.3	1.5	NA	NA	NA	NA	NA	NA
	24-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.1	1.6	2.6	NA	NA	NA
	02-Nov-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.1	1.6	2.6	NA	NA	NA
	11-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.9	1.7	3.4	NA	NA	NA

Borehole No.	Sampling Date	U-238			U-234			Uranium			Ra-226			U-235		
		mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mg/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
SRK-KG2	16-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.8	1.8	1.1	NA	NA	NA
	16-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.7	1.7	0.8	NA	NA	NA
SRK-KG4	21-May-08	4.1	2.5	7.5	29.4	5.9	9.5	NA	NA	NA	83.0	6.3	3.4	0.2	0.1	0.4
	05-Nov-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	92.3	6.1	4.3	NA	NA	NA
	01-May-11	4.4	1.4	1.2	12.6	2.4	1.2	0.4	0.3	1.5	23.2	3.1	1.1	0.2	0.1	0.1
	01-Nov-11	NA	NA	NA	NA	NA	NA	0.8	0.0	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.5	0.1	1.5	NA	NA	NA	NA	NA	NA
	20-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	51.2	3.8	0.8	NA	NA	NA
	02-Nov-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	51.2	3.8	0.8	NA	NA	NA
	10-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	91.4	6.2	5.6	NA	NA	NA
	17-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	83.1	5.7	1.1	NA	NA	NA
	17-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	98.2	6.2	1.1	NA	NA	NA
SRK-KG6	21-May-08	3.5	6.1	26.0	38.3	11.6	9.5	NA	NA	NA	34.9	4.1	1.3	0.2	0.3	1.2
	05-Nov-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	44.6	4.6	5.3	NA	NA	NA
	01-May-11	15.0	4.3	3.4	14.4	4.3	3.4	0.6	0.3	1.5	57.6	4.1	0.8	0.7	0.2	0.2
	01-Nov-11	NA	NA	NA	NA	NA	NA	0.9	0.0	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.4	0.2	1.5	NA	NA	NA	NA	NA	NA
	25-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	36.8	3.4	2.3	NA	NA	NA
	01-Nov-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	36.8	3.4	2.3	NA	NA	NA
	10-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	47.3	4.2	3.1	NA	NA	NA
	17-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	54.5	4.7	1.1	NA	NA	NA
	17-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	56.7	4.6	1.0	NA	NA	NA
SRK-KG8	21-May-08	13.0	4.1	9.3	19.4	4.5	2.7	NA	NA	NA	24.7	2.9	2.4	0.6	0.2	0.4
	05-Nov-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	25.2	3.5	1.3	NA	NA	NA
	01-May-11	18.8	5.2	3.9	35.2	7.2	3.9	0.8	0.1	1.5	39.3	3.5	0.9	0.9	0.2	0.2
	01-Nov-11	NA	NA	NA	NA	NA	NA	4.2	0.2	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.7	0.0	1.5	NA	NA	NA	NA	NA	NA
	20-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	33.4	3.2	0.8	NA	NA	NA
	01-Nov-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	33.4	3.2	0.8	NA	NA	NA
	10-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	32.0	3.7	5.6	NA	NA	NA

Borehole	Sampling	U-238			U-234			Uranium			Ra-226			U-235		
No.	**Date**	**mBq/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**	**mg/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**	**mBq/ℓ**	**1θ**	**MDA**
SRK-KG8	16-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	40.2	4.0	1.1	NA	NA	NA
	16-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	35.0	4.2	1.4	NA	NA	NA
SRK-KG9	21-May-08	12.0	7.2	22.0	29.0	10.3	22.0	NA	NA	NA	75.7	6.2	5.1	0.5	0.3	1.0
	05-Nov-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	78.5	6.3	1.4	NA	NA	NA
	01-May-11	36.1	7.4	4.1	66.1	10.1	4.1	0.1	0.3	1.5	77.3	5.0	0.9	1.7	0.3	0.2
	01-Nov-11	NA	NA	NA	NA	NA	NA	0.9	0.1	0.1	NA	NA	NA	NA	NA	NA
	01-May-12	NA	NA	NA	NA	NA	NA	0.4	0.2	1.5	NA	NA	NA	NA	NA	NA
	25-Jul-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	63.2	4.8	2.7	NA	NA	NA
	02-Nov-17	NA	NA	NA	NA	NA	NA	NA	NA	NA	63.2	4.8	2.7	NA	NA	NA
	10-Apr-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	43.8	3.9	2.6	NA	NA	NA
	16-Oct-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	80.7	5.3	0.9	NA	NA	NA
	16-Oct-19	NA	NA	NA	NA	NA	NA	NA	NA	NA	92.4	5.8	1.0	NA	NA	NA
Malmesbury Aquifer BHS	**Minimum**	**3.39**			**5.87**			**0.14**			**6.05**			**0.16**		
	Maximum	**36.10**			**66.10**			**4.22**			**271.00**			**1.66**		
	Median	**12.00**	**4.30**	**4.10**	**19.40**	**5.10**	**3.40**	**0.74**	**0.15**	**1.50**	**52.85**	**4.60**	**1.40**	**0.55**	**0.20**	**0.19**
Malmesbury Aquifer Nucl1 Illustrative Footprint BHs KG01, KG03, KG04 & KG6	**Minimum**	**3.39**			**5.87**			**0.36**			**6.05**			**0.16**		
	Maximum	**19.80**			**38.30**			**2.28**			**271.00**			**0.91**		
	Median	**8.20**	**3.40**	**5.45**	**16.25**	**4.70**	**2.90**	**0.65**	**0.18**	**1.50**	**51.20**	**4.40**	**1.25**	**0.38**	**0.16**	**0.26**

mBq/ℓ = milli Becquerel per litre MDA = Minimum Detectable Activity Concentration 1θ = 1 sigma = uncertainty calculated mainly from counting statistics NA = Not analysed

Table 5.11.28
Radionuclide Analyses Continued: Malmesbury Aquifer Monitoring

Borehole	Sampling	Ra-223			Th-232			Ra-224			Gross α activity			Gross β activity		
No.	Date	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
PBMR1	01-May-11	2.1	2.6	3.5	0.9	0.0	1.5	2.6	1.3	1.8	-63	280	950	-35	200	650
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-800	1100	3700	6780	530	1500
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-410	350	1200	300	300	1000
	25-Jul-17	-0.4	2.4	1.3	NA	NA	NA	5.4	2.8	7.8	81	120	400	290	130	410
	31-Oct-17	-0.4	2.4	1.3	NA	NA	NA	5.4	2.8	7.8	110	62	200	904	106	270
	09-Apr-18	-22.0	3.8	4.1	NA	NA	NA	0.8	1.8	7.3	188	64	180	466	90	260
	15-Oct-18	-3.5	4.9	2.0	NA	NA	NA	11.4	3.6	3.1	203	70	200	736	100	270
	15-Oct-19	-2.7	3.5	1.1	NA	NA	NA	4.7	1.8	1.8	10	44	170	69	83	280
SRK-KG1	21-May-08	-7.4	17.0	17.0	8.3	5.9	11.0	21.7	6.3	4.9	-140	570	1900	1160	250	790
	05-Nov-08	19.4	3.5	5.7	NA	NA	NA	16.9	3.4	1.9	-100	150	220	1360	250	150
	01-May-11	0.5	3.0	1.0	0.7	0.2	1.5	2.9	1.7	2.6	-450	120	500	170	180	600
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-520	1300	4400	3510	490	1500
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-440	360	1200	580	310	1000
	20-Jul-17	-5.5	3.1	2.3	NA	NA	NA	11.4	3.2	2.4	-6	140	490	634	135	420
	01-Nov-17	-5.5	3.1	2.3	NA	NA	NA	11.4	3.2	2.4	311	93	260	841	98	230
	11-Apr-18	-40.0	4.9	4.8	NA	NA	NA	8.4	2.7	7.0	370	91	230	874	97	230
	17-Oct-18	7.0	4.4	1.1	NA	NA	NA	44.5	7.3	3.3	200	78	230	855	96	230
	17-Oct-19	10.9	7.5	1.4	NA	NA	NA	13.0	3.4	2.3	411	94	230	981	101	220
SRK-KG2	21-May-08	0.6	2.5	4.1	28.1	7.8	5.8	< MDA		4.1	-250	340	1200	1520	240	760
	05-Nov-08	-0.4	1.4	3.8	NA	NA	NA	5.6	3.3	10.0	-120	110	160	819	236	150
	01-May-11	11.4	7.6	9.1	0.9	0.3	1.5	< MDA		14.0	-220	57	230	150	170	580
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-390	700	2200	4130	460	1400
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-360	190	640	430	290	960
	24-Jul-17	1.3	1.0	1.2	NA	NA	NA	9.5	3.5	7.7	11	61	210	80	120	400
	02-Nov-17	1.3	1.0	1.2	NA	NA	NA	9.5	3.5	7.7	31	40	140	360	77	230
	11-Apr-18	1.3	1.6	4.7	NA	NA	NA	6.6	2.6	7.1	97	46	140	318	76	230

Borehole	Sampling	Ra-223			Th-232			Ra-224			Gross α activity			Gross β activity		
No.	Date	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
SRK-KG2	16-Oct-18	1.1	1.0	1.2	NA	NA	NA	1.4	1.4	3.7	30	39	140	384	78	230
	16-Oct-19	0.6	1.3	1.1	NA	NA	NA	<MDA		1.8	62	30	93	308	67	200
SRK-KG4	21-May-08	15.0	10.0	270.0	6.6	4.7	15.0	7.1	3.5	4.8	-180	420	1400	1490	250	770
	05-Nov-08	6.6	4.5	2.1	NA	NA	NA	10.2	3.2	6.2	-49	140	210	871	242	150
	01-May-11	2.6	1.7	1.2	0.4	0.3	1.5	1.3	1.3	3.4	-370	76	320	-100	170	590
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-470	800	2700	4690	480	1400
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-270	280	950	420	300	980
	20-Jul-17	2.8	2.0	2.3	NA	NA	NA	10.2	3.2	6.4	230	120	380	400	130	410
	02-Nov-17	2.8	2.0	2.3	NA	NA	NA	10.2	3.2	6.4	195	65	180	290	78	240
	10-Apr-18	-14.0	4.1	6.3	NA	NA	NA	11.6	3.3	6.1	417	82	190	426	83	240
	17-Oct-18	-3.5	2.0	1.2	NA	NA	NA	7.8	3.2	3.5	260	73	190	493	85	240
	17-Oct-19	4.0	4.5	1.4	NA	NA	NA	5.8	2.2	2.2	54	44	150	265	69	210
SRK-KG6	21-May-08	28.0	7.9	3.5	6.7	2.4	2.3	9.1	4.1	4.9	-240	420	1400	600	240	770
	05-Nov-08	14.8	5.2	6.8	NA	NA	NA	5.8	2.4	2.6	-26	140	210	875	242	150
	01-May-11	3.1	2.0	0.9	0.6	0.3	1.5	1.8	1.3	2.5	-300	92	370	11	180	590
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-540	900	3100	3800	470	1400
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-450	270	920	340	300	980
	25-Jul-17	-0.7	1.5	2.6	NA	NA	NA	5.4	2.6	6.8	-22	110	380	260	130	410
	01-Nov-17	-0.7	1.5	2.6	NA	NA	NA	5.4	2.6	6.8	-150	54	250	690	100	270
	10-Apr-18	-0.1	3.2	1.9	NA	NA	NA	7.0	2.9	8.3	-25	64	240	220	85	270
	17-Oct-18	1.4	2.1	1.2	NA	NA	NA	9.3	3.5	3.6	-86	54	230	520	93	270
	17-Oct-19	0.9	3.3	1.3	NA	NA	NA	2.4	1.4	2.2	91	49	160	306	71	210
SRK-KG8	21-May-08	1.4	2.9	2.0	7.9	4.2	12.0	1.4	1.0	2.0	-300	450	1500	2080	250	780
	05-Nov-08	53.4	6.8	9.5	NA	NA	NA	3.3	2.4	8.0	-300	140	210	927	243	150
	01-May-11	2.1	1.7	1.0	0.8	0.1	1.5	< MDA		2.7	-280	99	390	47	180	590
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-390	900	3100	768	443	1400
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-410	270	920	420	300	980
	20-Jul-17	2.0	1.7	2.5	NA	NA	NA	4.6	2.1	2.5	-19	96	340	230	130	410
	01-Nov-17	2.0	1.7	2.5	NA	NA	NA	4.6	2.1	2.5	-10	57	220	170	72	230
	10-Apr-18	-1.4	2.8	5.3	NA	NA	NA	-0.1	2.2	9.3	42	59	210	321	76	230

Borehole No.	Sampling Date	Ra-223			Th-232			Ra-224			Gross α activity			Gross β activity		
		mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA	mBq/ℓ	1θ	MDA
SRK-KG8	16-Oct-18	1.6	1.8	1.2	NA	NA	NA	5.2	2.6	3.5	-38	55	220	381	78	230
	16-Oct-19	3.4	3.3	1.8	NA	NA	NA	6.6	2.7	3.0	-32	40	170	-300	89	320
SRK-KG9	21-May-08	-10.0	9.7	17.0	8.7	3.1	2.9	18.3	5.8	5.0-	-190	430	1500	1750	250	770
	05-Nov-08	15.9	6.7	6.0	NA	NA	NA	13.4	3.9	3.0	-210	140	210	851	242	150
	01-May-11	0.2	2.1	1.0	0.1	0.3	1.5	2.0	1.4	2.7	-170	97	370	85	180	590
	01-Nov-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	-610	900	3000	441	440	1400
	01-May-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	-380	270	910	360	300	980
	25-Jul-17	1.2	2.2	1.3	NA	NA	NA	8.7	3.1	2.9	28	110	380	170	130	410
	02-Nov-17	1.2	2.2	1.3	NA	NA	NA	8.7	3.1	2.9	91	57	190	254	73	230
	10-Apr-18	-7.6	2.7	4.9	NA	NA	NA	2.2	1.6	5.4	310	67	160	438	78	220
	16-Oct-18	-1.5	2.0	1.0	NA	NA	NA	8.0	3.0	3.1	92	58	190	378	77	230
	16-Oct-19	-1.3	4.0	1.3	NA	NA	NA	4.6	1.9	2.1	281	66	160	344	76	230
All Malmesbury Aquifer BHS	**Minimum**	**-40.0**			**0.1**			**-0.1**			**-800**			**-300**		
	Maximum	**53.4**			**28.1**			**44.5**			**417**			**6780**		
	Median	**1.2**	**2.8**	**2.1**	**0.9**	**0.3**	**1.5**	**6.6**	**2.8**	**3.5**	**-44**	**98**	**245**	**423**	**133**	**360**
Malmesbury Aquifer Nucl-1 Illustrative Footprint BHs KG01, KG03, KG04 & KG6	**Minimum**	**-40.0**			**0.4**			**1.3**			**-540**			**-100**		
	Maximum	**28.0**			**28.1**			**44.5**			**417**			**4690**		
	Median	**1.3**	**3.1**	**2.3**	**3.8**	**1.4**	**1.9**	**8.4**	**3.2**	**4.5**	**-68**	**102**	**245**	**507**	**153**	**335**

mBq/ℓ = milli Becquerel per litre MDA = Minimum Detectable Activity Concentration 1θ = 1 sigma = uncertainty calculated mainly from counting statistics NA = Not analysed

Stable isotope (D/H, O-18/O-16) and H-3 analyses for the Malmesbury Aquifer groundwater are shown in ***Table 5.11.29*** for water samples taken during this SSR monitoring programme. The samples in ***Figure 5.11.21*** plot on, or just above the GMWL. This data trend indicates normal (i.e. not affected by isotopic processes) precipitation and recharge processes at the site and surrounding area.

Table 5.11.29
Summary of Isotope and Tritium Analyses: Malmesbury Aquifer

Borehole No.	Date Sampled	δ D (‰)	δ^{18}O (‰)	Tritium (TU)	
SRK-KG1	20/05/2008	-21.0	-4.07	0.8	±0.2
	03/11/2008	-19.6	-4.17	0.2	±0.2
	04/05/2009	NA	NA	0.4	±0.2
	25/05/2011	NA	NA	0.0	±0.2
	23/11/2011	NA	NA	0.2	±0.2
	23/05/2012	NA	NA	0.5	±0.2
	21/11/2012	NA	NA	0.2	±0.2
	30/05/2013	NA	NA	0.2	±0.2
	01/11/2013	NA	NA	0.4	±0.2
	20/07/2017	NA	NA	0.6	±0.2
	01/11/2017	NA	NA	0.4	±0.2
	11/04/2018	NA	NA	1.0	±0.3
	17/10/2018	NA	NA	0.4	±0.2
	17/10/2019	NA	NA	0.6	±0.2
	19/05/2020	NA	NA	0.3	±0.2
	20/10/2020	NA	NA	0.1	±0.2
SRK-KG4	20/05/2008	-20.8	-3.80	<0.2	±0.2
	03/11/2008	-20.8	-3.80	<1.0	±0.2
	04/05/2009	NA	NA	0.6	±0.2
	25/05/2011	NA	NA	0.0	±0.2
	23/11/2011	NA	NA	0.0	±0.2
	23/05/2012	NA	NA	0.2	±0.2
	21/11/2012	NA	NA	0.4	±0.2
	30/05/2013	NA	NA	0.0	±0.2
	20/07/2017	NA	NA	<0.2	±0.2
	02/11/2017	NA	NA	0.1	±0.2
	10/04/2018	NA	NA	0.3	±0.2
	15/10/2018	NA	NA	0.3	±0.2
	15/10/2019	NA	NA	0.6	±0.2
	20/05/2020	NA	NA	0.0	±0.2
	21/10/2020	NA	NA	1.0	±0.3
SRK-KG6	20/05/2008	-23.3	-4.32	0.3	±0.2
	03/11/2008	-21.2	-3.90	<1	±0.2
	04/05/2009	NA	NA	0.3	±0.2
	25/05/2011	NA	NA	0.0	±0.2
	23/11/2011	NA	NA	0.5	±0.2
	23/05/2012	NA	NA	0.0	±0.2
	21/11/2012	NA	NA	0.2	±0.2

Borehole No.	Date Sampled	δ D (‰)	δ^{18}O (‰)	Tritium (TU)	
SRK-KG6	30/05/2013	NA	NA	0.0	±0.2
	25/07/2017	NA	NA	<0.2	±0.2
	01/11/2017	NA	NA	0.2	±0.2
	10/04/2018	NA	NA	0.3	±0.2
	15/10/2018	NA	NA	0.5	±0.2
	15/10/2019	NA	NA	1.2	±0.3
	20/05/2020	NA	NA	0.0	±0.2
	20/10/2020	NA	NA	0.7	±0.2
SRK-KG9	20/05/2008	-21.4	-4.09	0.3	±0.2
	03/11/2008	-19.1	-3.71	<1	±0.2
	04/05/2009	NA	NA	1.3	±0.3
	25/05/2011	NA	NA	0.0	±0.2
	23/11/2011	NA	NA	0.4	±0.2
	23/05/2012	NA	NA	0.4	±0.2
	21/11/2012	NA	NA	0.4	±0.2
	30/05/2013	NA	NA	0.3	±0.2
	25/07/2017	NA	NA	<0.2	±0.2
	02/11/2017	NA	NA	1.2	±0.3
	10/04/2018	NA	NA	0.9	±0.2
	16/10/2018	NA	NA	0.4	±0.2
	16/10/2019	NA	NA	0.5	±0.2
	19/05/2020	NA	NA	0.3	±0.3
	20/10/2020	NA	NA	0.2	±0.2
Minimum		-23.30	-4.32	0.0	
Maximum		-19.10	-3.71	1.3	
Median		-20.90	-3.99	0.3	

NA = Not analysed

The H-3 values are generally very low, ranging from 0 to 0.6 TU, indicating predominantly pre-1952 water, although some higher values were observed, coinciding with a ‘very wet’ year in 2014 (see earlier definition of this term). These higher values indicate a component of relatively recent recharge which could indicate mixing with Sandveld Aquifer groundwater given that direct recharge to the Malmesbury Aquifer is postulated to occur on outcrop areas inland from the site.

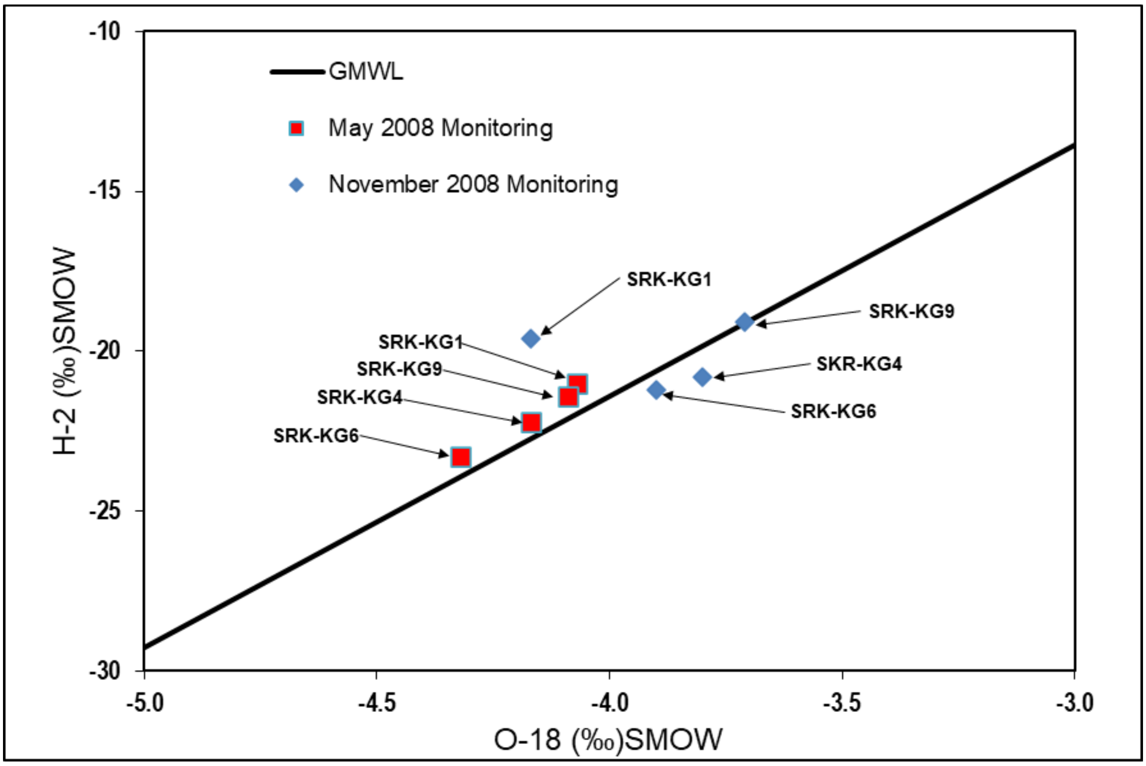


Figure 5.11.21
O-18 versus H-3: Hydrocensus Samples: Malmesbury Aquifer

Adsorption testing

One sample, KG-Comp 3, representing the secondary Malmesbury Aquifer (shale) underlying the site was submitted for adsorption testing. The sample was submitted to Necsa for the determination of the partition coefficients of selected radionuclides (Cs-137, Co-60, Sr-90 and U). The K_d values determined for the site shale sample are summarised in ***Table 5.11.30*** and the Necsa analytical report is given in ***Appendix 5.11.I***.

Low K_d values were measured for the Cs-137 tracer species for the sample with relatively small differences in K_d at the different pH values. The K_d values for Co-60 show large differences at different pH values. The measured value at pH 3 was low, moderate at pH 12 and high at pH 7. Low K_d values were measured for the Sr-90 tracer species for the sample with small differences in K_d value at pH 7 and 12, but lower at pH 3. Relatively high K_d values for the different uranium tracer species were measured at pH 7 and 12 for the sample. At pH 3 the measured K_d value was low.

Table 5.11.30
Partition Coefficients for Selected Radionuclides at Different pH Values

Isotope/element	K_d (mℓ/g)		
Sample	**pH 3**	**pH 7**	**pH 12**
Cs-137			
KG-Comp 3 (shale)	1.00	7.90	5.92
Co-60			
KG-Comp 3 (shale)	3.38	4.07	89.80
Sr-90			
KG-Comp 3 (shale)	$6.07x\ 10^{-1}$	2.39	3.34
U			
KG-Comp 3 (shale)	2.54	815	910
mℓ/g = millilitre per gram			

Given the natural pH of the site groundwater, which ranges from 6.5 to 8.1, the retardation of Cs-137 and Sr-90 in the aquifer is expected to be low. The rate of migration of both Co-60 and dissolved U species are likely to be moderately retarded relative to that of conservative species (H-3). These are broad conclusions which are constrained by the limited analyses done at this stage and the difference in conditions between the laboratory and *in situ* conditions. The Sr-90 K_d values will be used in the scenario modelling.

5.11.7 Modelling

To assist in the characterisation of the existing groundwater regime and the evaluation of possible future changes and impacts on the site under different scenarios, e.g. abstraction, construction dewatering and climate change, a numerical flow model was developed. This was carried out in two stages, following standard international practice (Harbaugh & McDonald, 1996), viz.:

- conceptual model;
- numerical flow model.

Once the flow model was suitably set-up and calibrated to the required accuracy, scenario modelling was carried out as a third stage.

5.11.7.1 Conceptual Model

Having collated all available information related to the site and the surrounding areas and carried out detailed site investigations, a conceptual model was developed. This is in terms of aquifers/aquitards, boundaries, recharge, borehole data, groundwater levels/contours and flow directions and quality, and assigns hydraulic parameters to the various formations, i.e.

hydraulic conductivity, transmissivity and storage. The development of a conceptual geohydrological model for the site and its surroundings takes into consideration all the information presented in the preceding sections.

A conceptual geohydrological block-model and cross-sections of the site and its immediate surroundings is presented in ***Drawing 5.11.11*** and ***Figure 5.11.23***, respectively. The block-model shows general features from east-northeast inland to west-southwest at the coast, and their juxtaposition, while the cross-sections show more geohydrological information such as recharge and K values.

The main cross-section (1) is a schematic representation based on borehole information and extrapolations, whereas the site-specific cross-section (2) is based on SSR borehole logs (geohydrological and geotechnical). As can be seen, the KNPS and illustrative Nuclear-1 installation footprint area are located very close to the coastline. In terms of the hydrological/groundwater cycle, this means that the nuclear installation(s)/KNPS will likely be located in or close to a groundwater discharge zone. Taking this and data from the investigations performed on site for this SSR into account, the following characteristics were assumed in the conceptual model:

- there is no downstream use of groundwater apart from some ecological dependence;
- groundwater at the site is near/at the end of its flow path;
- groundwater levels are shallow;
- there should be an upward component of groundwater flow towards the water table, although artificial recharge may cause local deviations from this trend;
- the receiving environment/downstream receptor of any contamination will be the shore zone/sea;
- there is a two-aquifer system present, with an upper intergranular and a lower fractured rock aquifer;
- the aquifers are in weak hydraulic connection and are separated by a weathered zone in the bedrock, referred to in this report as the Malmesbury Aquitard;
- local direct recharge only affects the Sandveld Aquifer - The Malmesbury Aquifer is recharged inland, far from the site boundaries. There may be upward leakage of groundwater from the Malmesbury Aquifer into the Sandveld Aquifer (and *vice versa*) depending on relative groundwater heads in each aquifer.

- groundwater flow rates are relatively low in the sand layer aquifer, very low in the fractured aquifer ‘matrix’ and intermediate in individual or discrete fractures - However, the fractured aquifer is modelled as one unit for the purposes of this SSR.

- 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 the site in terms of establishing the nuclear installation(s). This is to be expected given the height of the water table above sea level (z) and the Ghyben-Herzberg relationship (interface = 40z), as previously described. The interface is therefore below the base of the Sandveld Aquifer and the top of the solid bedrock, into which the nuclear installation foundations will be founded, as was the case with the KNPS.

- natural groundwater quality is marginally saline and of a mixed NaCl and $Ca(HCO_3)_2$ character.

In order to set up a groundwater flow model, a water level contour map must first be generated. An interpolation technique, using the available data, was used to simulate water levels over the entire model area. The interpolation technique used is referred to as Bayesian interpolation[9] where water levels are correlated with topographic elevation. All available levels were plotted against elevation as shown in ***Figure 5.11.22***. The results indicate a correlation of 96 per cent between the data sets, although this is not necessarily apparent from the conceptual model or cross-section. Therefore, Bayesian interpolation is valid and was used to calculate water levels for the entire model area (Panday, C.D. Niswonger, R.G. Ibaraki, M. and Hughes, J.D., 2013).

[9] Bayesian interpolation is a geostatistical interpolation method that can be applied to generate groundwater levels where measured water levels can be correlated with topographic elevation. This is usually valid for unconfined aquifers.

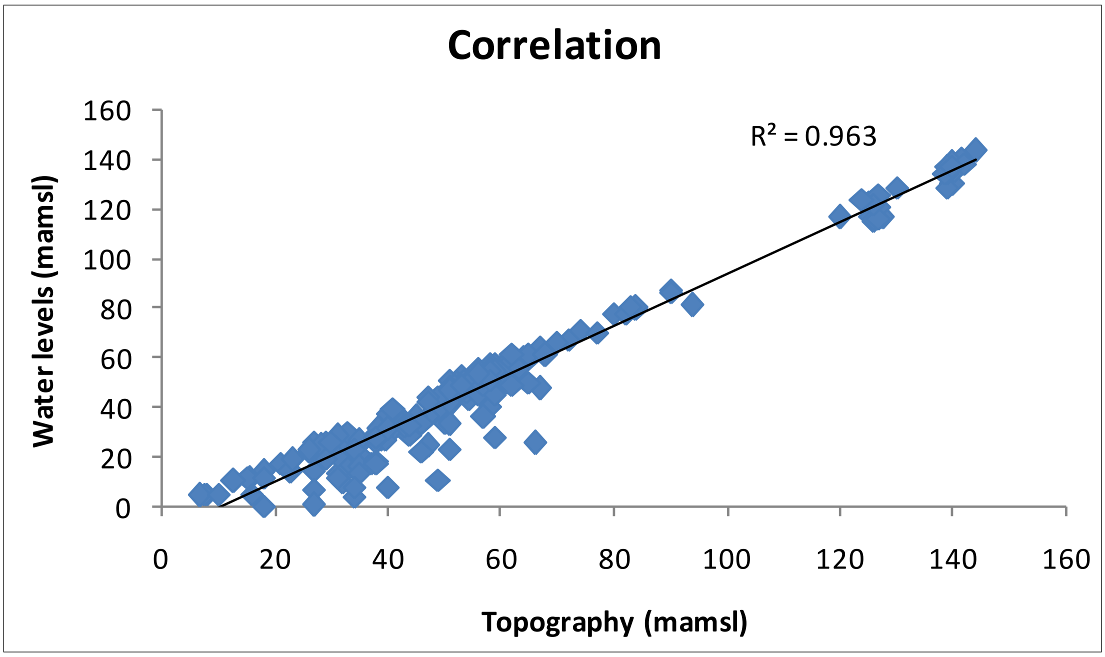
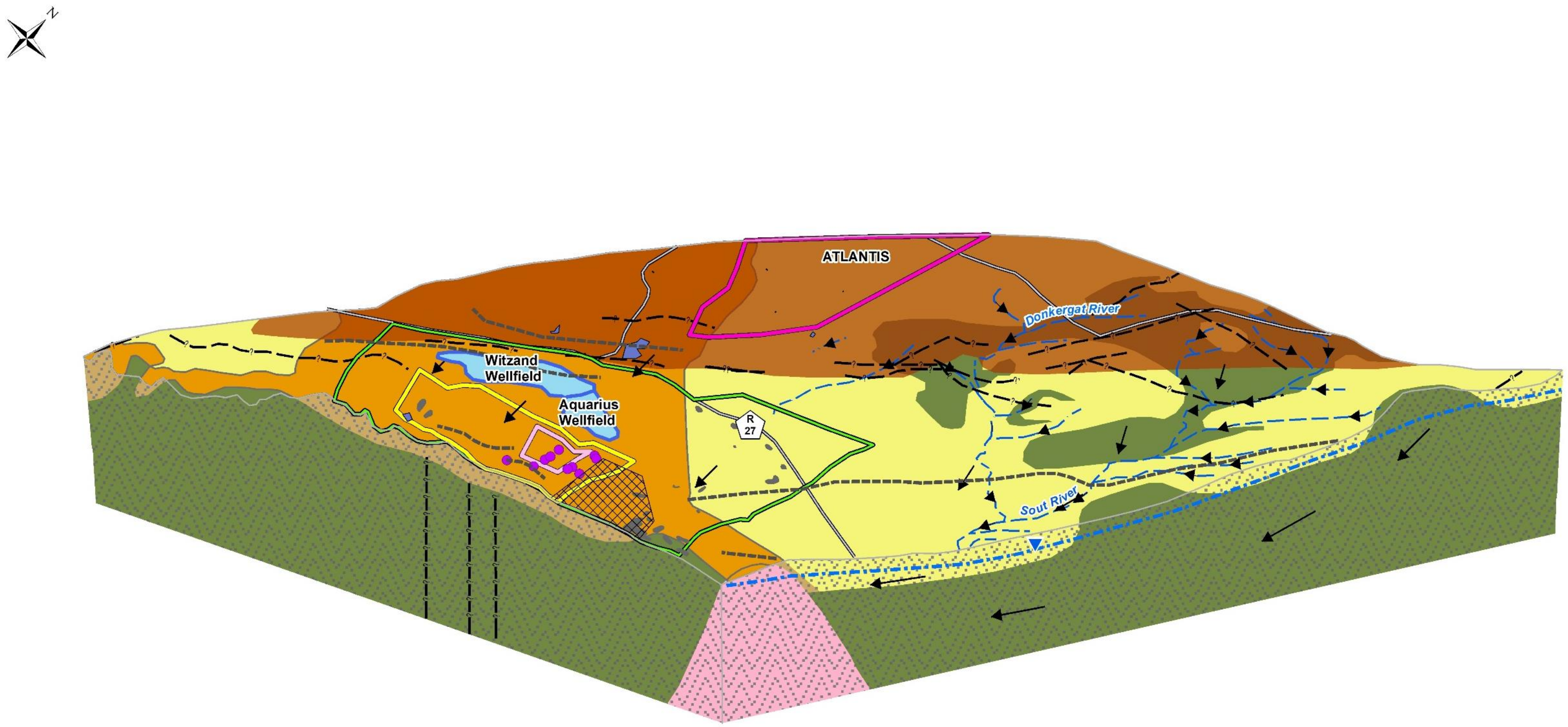


Figure 5.11.22
Correlation Between Groundwater Levels and Topography

As groundwater levels are higher at higher elevation and flow is to lower topography, i.e. towards the ocean, it can be assumed that groundwater flow takes place under generally unconfined to semi-confined conditions. This has also been corroborated by the aquifer characterisation data presented in the preceding subsections. Model calibration and validation are required to translate the usually relatively limited and point source data to a regional scale. They also facilitate the simplification of the natural system in the model. In model calibration, simulated values such as water levels or contaminant concentrations are compared with field measurements. The model input data were altered within reasonable ranges based on geohydrological and modelling experience and the available site information, until the simulated and observed values were in correspondence with an acceptable tolerance.



Simplified Geohydrology

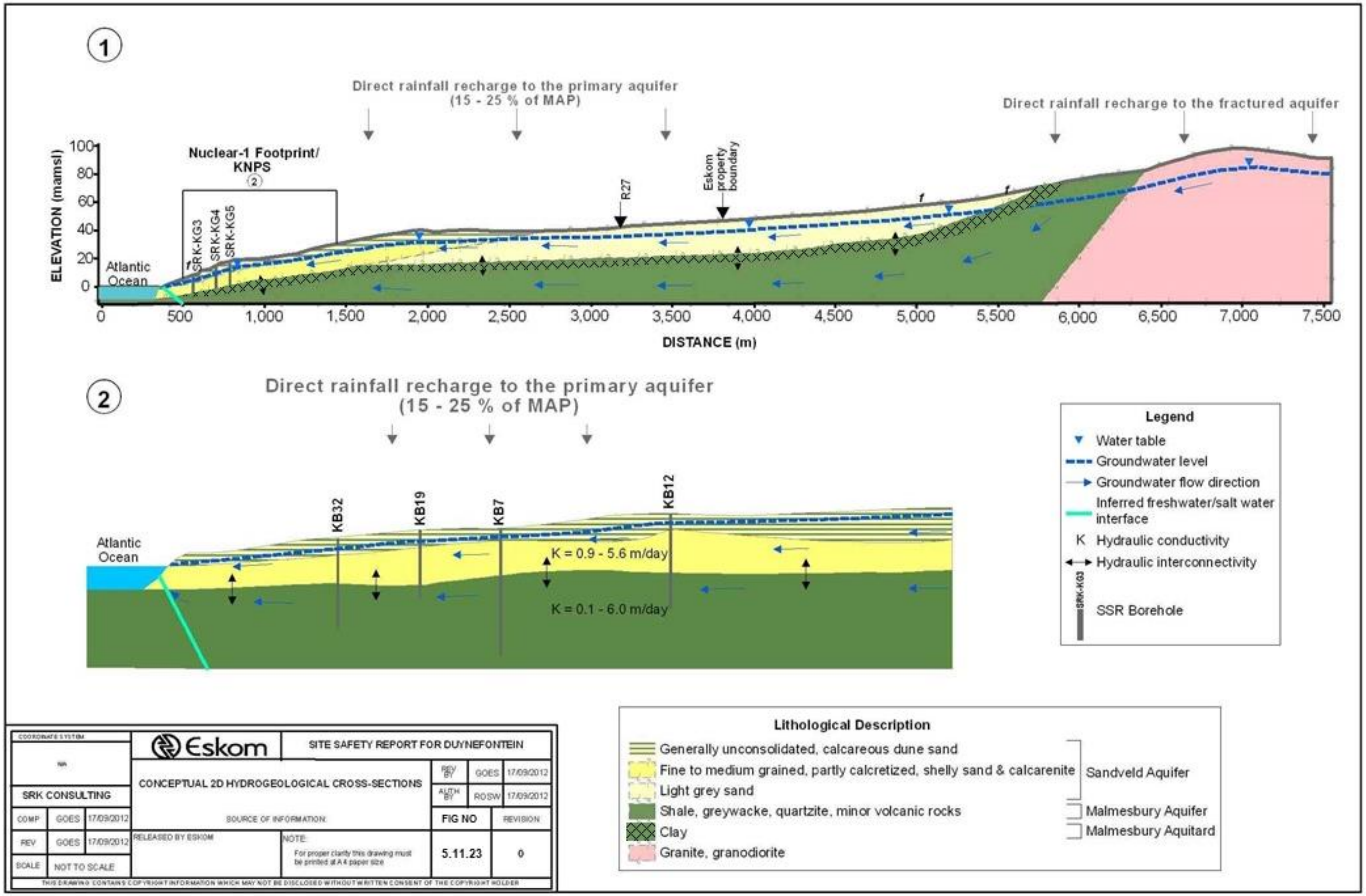
- Inferred granite intrusive suboutcrop
- Sandveld Aquifer
- Quaternary Deposits
- Sandveld Aquifer
- Malmesbury Aquifer
- Cape Granite Suite

Legend

- SSR Boreholes
- Inferred water table
- Roads
- Rivers
- Inferred faults
- Inferred dykes
- Inferred groundwater flow direction
- Inferred groundwater elevation
- Wetlands
- Artificial Recharge Basins
- Wellfields
- Atlantis
- Duynefontyn Site
- Enveloping Footprint
- Koeberg Nuclear Power Station
- Illustrative Nuclear Island Footprint

COORDINATE SYSTEM			Eskom	SITE SAFETY REPORT FOR DUYNEFONTYN			
N/A			CONCEPTUAL GEOHYDROLOGICAL BLOCK MODEL		REV BY	ROSW	30/04/2021
SRK CONSULTING					AUTH BY	ROSW	27/01/2021
COMP	BURK	31/08/2010	SOURCE OF INFORMATION:		DWG NO		REVISION
REV	BRCH	30/04/2021	RELEASED BY ESKOM	NOTE: For proper clarity this drawing must be printed at A3 paper size	5.11.11		3
SCALE	Not to scale						

Path: \\CTN-SVR0.ctn.za.srk.ad\vol1\Root\Proj\New Proj\507052_SSR UPDATE\8GIS\GISPROJ\MXD\Duynefontyn\Chapter 5\Section 5-11 Geohydrology\507052_DWG_5-11-11_DSSR UPDATE_ConceptualModel_Profile_A3L_Rev3_20210430.mxd



1
Direct rainfall recharge to the primary aquifer
(15 - 25 % of MAP)
Direct rainfall recharge to the fractured aquifer
ELEVATION (mamsl)
Nuclear-1 Footprint/
KNPS
2
SRK-KG3
SRK-KG4
SRK-KG5
R27
Eskom property boundary
Atlantic Ocean
DISTANCE (m)
2
Direct rainfall recharge to the primary aquifer
(15 - 25 % of MAP)
KB32
KB19
KB7
KB12
Atlantic Ocean
K = 0.9 - 5.6 m/day
K = 0.1 - 6.0 m/day
Legend
Water table
Groundwater level
Groundwater flow direction
Inferred freshwater/salt water interface
K Hydraulic conductivity
Hydraulic interconnectivity
SSR Borehole
Lithological Description
Generally unconsolidated, calcareous dune sand
Fine to medium grained, partly calcretized, shelly sand & calcarenite
Light grey sand
Shale, greywacke, quartzite, minor volcanic rocks
Clay
Granite, granodiorite
Sandveld Aquifer
Malmesbury Aquifer
Malmesbury Aquitard
Eskom
SITE SAFETY REPORT FOR DUYNEFONTEIN
CONCEPTUAL 2D HYDROGEOLOGICAL CROSS-SECTIONS
SRK CONSULTING
COMP GOES 17/09/2012
REV GOES 17/09/2012
SCALE NOT TO SCALE
REV BY GOES 17/09/2012
AUTH BY ROSW 17/09/2012
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5.11.7.2 Numerical Model

A numerical flow model has been developed for the site to replicate as near as practically possible the natural geohydrological conditions existing at the site and surrounding catchment(s)/study area. Once an acceptable correspondence of the simulated data to the site data was achieved, as indicated by comparison and sensitivity analysis (validation and verification - V&V. See ***Appendix 5.11.J***), scenario modelling was carried out.

Scenario Modelling Objectives

The objectives of scenarios modelled for this SSR were to:

- assess the potential dewatering requirements during construction and determine the zone of drawdown and area of influence as a result of dewatering of the foundation excavation (scenario 1) - This scenario also indicates possible quantities of groundwater that will be available from dewatering for construction purposes;
- evaluate the effect of predicted sea level rise on dewatering/groundwater control (scenario 2);
- evaluate the effect of predicted sea level rise and climate change related increases in rainfall and therefore recharge on the site groundwater system (scenario 3);
- assess the amount of groundwater available for possible water supply to the nuclear installation(s) under wet, average and drought conditions (scenario 4);
- assess the potential extent of seawater intrusion due to dewatering (scenario 5);
- assess the transport of contamination/radionuclides from the nuclear installation(s) in groundwater under natural conditions and with pumping from the Aquarius and Witzand wellfields (it is assumed that SSR boreholes will not be used for site construction supply) (scenario 6).

Model Selection

In order to investigate the behaviour of aquifer systems in time and space, the mathematical model *MODFLOW-USG* was selected for the evaluation of the site. *MODFLOW-USG* (Panday, C.D. Niswonger, R.G. Ibaraki, M. and Hughes, J.D., 2013) is a modular three-dimensional finite difference groundwater flow model, which was developed by the U.S. Geological Survey. It is an internationally accepted and benchmarked modelling tool, which is used for calculation of the solution of the groundwater flow equation using the finite difference approach. A professional graphical interface

Groundwater Vistas, developed by Environmental Simulations, Inc, (Rumbaugh, J. and Rumbaugh, D., 2019) was also used to apply the model to the site, and to analyse and to display the modelling results.

The reasons for the selection of *MODFLOW* as the modelling tool for this SSR and more specifically *Groundwater Vistas* as the graphical interface are the following:

- *MODFLOW* simulates steady and non-steady state flow in an irregularly shaped flow system. In this system the aquifer layers can be confined, unconfined, or a combination of the two;
- Flow from external stresses (e.g. flow to boreholes, aerial recharge, evapotranspiration, flow to drains, and flow through river beds) can be simulated;
- Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic;
- The storage coefficient/specific storage may be heterogeneous;
- Internationally, *MODFLOW* is currently the most used numerical model for groundwater flow solutions;
- The flow equations incorporated in the model provide a reasonable approximation of the aquifer conditions prevalent on site, particularly in the Sandveld Aquifer, which will have the main influence on site development;
- *MODFLOW* was successfully used for the dewatering simulations for the KNPS (Eskom, 2006) and planned PBMR DPP (Council for Scientific and Industrial Research, 2000) and to simulate the Atlantis Aquifer for management support for groundwater abstraction (Council for Scientific and Industrial Research, 2017).

Other modelling packages such as *FEFLOW*, *FLAC* and *AQUA3D* were considered and each has its own strengths and weaknesses for this particular application. This evaluation is elaborated on in the V&V report in ***Appendix 5.11.J***. These and other specialist packages should be further evaluated for suitability for the detailed modelling that will be required for actual dewatering/groundwater control system design and long-term groundwater control measures for the nuclear installation(s).

Calibration

Calibration is required to account for unmeasured, unknown or unrepresented conditions or processes and uncertainty in measured input data. In model calibration, simulated values of long-term average rest water levels, seasonal fluctuations and flow rates were compared with field measurements. The model input data were then altered within reasonable ranges based on the modeller's experience and available information, until the simulated and observed values fitted within a reasonable tolerance.

The steady state head distribution is dependent upon the recharge, K, sources, sinks and boundary conditions specified. For a given recharge component and set of boundary conditions, the head distribution across the aquifer under steady-state conditions can be obtained for a specific K value. The simulated head distribution can then be compared to the measured head distribution and the K or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained. During modelling, the calibration was rapidly assessed by applying correlation using a best fit line between observed and simulated water level data. The root mean squared error indicates a correlation of 93 per cent between observed and simulated water level data for 191 borehole locations. This is considered to be acceptable for a model of this scale and with the large number of boreholes included and variability of aquifer conditions. The groundwater model has a large lateral extent compared to vertical extent and the water level is shallow in most areas.

The water flow mass balance for the calibrated regional steady state model is shown in ***Table 5.11.31***. Most inflows in the model area are from natural recharge (through percolation of water from rainfall). The Atlantis recharge basins account for approximately 7 ℓ/s additional inflow. This reflects the estimation of average estimated inflows for basin 12 and the coastal basins, as reported in (Council for Scientific and Industrial Research, 2017). Outflows include approximately 53 ℓ/s to borehole abstraction, and the rest is split between approximately two thirds flowing to the rivers (for entire model domain not just the site area) and one third flowing directly into the ocean. The mass balance error (per cent difference between inflows and outflows) is approximately 0.001 per cent which is well within the normal acceptance criterion of <0.5 per cent.

Table 5.11.31
Mass Balance for Calibrated Steady State Model

Parameter	Inflows (ℓ/s)	Outflows (ℓ/s)
Natural Recharge	752	0
Artificial Recharge	7	0
Borehole Abstractions	0	53
Flow to Rivers	0	472
Flow to Sea	0	234
Total	**759**	**759**
% Error	**0.001%**	

Following steady state calibration, transient model scenarios were run to simulate the time period from January 2008 to July 2018, as this is a period for which the most data was available regarding rainfall, observed wellfield abstraction rates and water level monitoring data. The modelled water level trends generally mimic the observed data very closely, with just a few occasions where water levels are slightly too high or too low compared to the observed. Further confidence in the successful calibration of the models is also demonstrated within the dewatering model scenarios, where the predicted inflows with the cut-off wall is 20 ℓ/s which is very similar to those measured at KNPS (21 ℓ/s) during actual dewatering for the nuclear installation excavation.

Validation and Verification

All computer codes used in simulation of processes associated with nuclear site safety assessments must undergo a thorough V&V process. Validation is the confirmation that the calculation method is fit for purpose, while verification shows that the controlling physical equations have been correctly translated into the software code.

The V&V report for the geohydrological modelling is in ***Appendix 5.11.J*****.** The information presented in the V&V report demonstrates the following:

- An adequate software code selection process was followed.
- The software code chosen, MODFLOW, is the most widely used groundwater flow modelling code internationally.
- Benchmark uses including use for the regional flow modelling by the USGS for the Yucca Mountain nuclear waste repository in the USA (Sinton, 1987).

- Modelled results obtained for groundwater levels compare favourably with actual measured values (long term averages and seasonal variation), giving confidence in the results of the predictive scenario modelling carried out.

- Geohydrology is not an exact science and outputs from the modelling give a qualitative indication of likely conditions, not an absolute prediction.

- The flow modelling was undertaken by suitably qualified and experienced practitioners and was adequately peer reviewed.

Thus, the model was found to be 'fit for purpose' to run predictive scenarios.

Predictive Scenario Assumptions

The following assumptions have been taken for the implementation of the model predictive scenarios:

- Key dates in terms of site activities are:

  - KNPS: extension of operation to 2044 and decommissioned by 2064 (this does not impact on the Nuclear-1 modelling);

  - Nuclear-1: Operational from 2030 – 2110 and decommissioned by 2130.

  Most of these dates cannot be modelled specifically with any accuracy but are covered generically in the scenarios presented below.

- An approximation of the areal dimensions and depth of the excavation for Nuclear-1 is required. These details were not available at the time of the modelling and so a surrogate example was used at the suggestion of Eskom (personal communication. I. Saayman, Senior Scientist, Eskom). The example used was that of Hinkley Point C (Energy, 2011). The Appendix A1 drawings in this report show the dimensions of the various Nuclear Island buildings including the two reactors, safeguard buildings, fuel building and fuel hall. Using this information gives the following rounded-up surface dimensions for the Nuclear Island:

  c.500 m x *c*.150 m

  Looking at the KNPS dewatering plan, which is ***Drawing 9.1*** of KSSR Rev 3 (Eskom, 2006) approximately 30 per cent of the excavation area is made up of slopes into the base of the excavation. Adding 30 per cent to the above dimensions gives:

  c.650 m x *c*.200 m

Looking at the positioning of the Nuclear Island buildings in relation to the nuclear footprint for Hinkley, indicates that the excavation should be positioned in the middle of the illustrative Nuclear-1 footprint supplied by Eskom. The depth of the excavation will be determined from the geological logs of the SSR boreholes in the Nuclear-1 footprint area.

- In the scenarios that include modelling of a bentonite-cement slurry cut-off wall surrounding the excavation area, the wall is assumed to have an average K of 1 x 10^{-9} m/s (8.6 x 10^{-3} m/d) (United States Society on Dams, 2011).
- In the scenarios that include modelling of climate change, sea level rise is assumed to be 2.3 m amsl by 2100. This is based on predictions contained in the Intergovernmental Panel on Climate Change Special Report (Intergovernmental Panel on Climate Change, 2019) and is further explained in ***Section 5.9***).
- Rainfall assumptions for the scenarios fall into one of the following categories (probabilistic values obtained from ***Section 5.8***):
  - average rainfall, which is taken to be *c*.371 mm/a, based on the long-term average rainfall (1980 – 2019) of the Koeberg Weather Station;
  - low rainfall (drought), based on the lowest year on record between 1980 and 2019, which is 2015, with a MAP of *c*.218 mm/a;
  - high rainfall, based on the probabilistically modelled rainfall data for the 1:100 year event, which equates to a MAP of *c*.623 mm/a;
  - climate-change related extreme rainfall which is based on the probabilistically modelled rainfall data for the 1:10^8 year event, which equates to a MAP of *c*.1 498 mm/a.
- Fracture zones exist within the site and regional area but on the scale of the regional and local scenario modelling it is considered that using equivalent hydraulic properties of a matrix will provide adequate representation of the system response. This is because the Malmesbury Aquifer is a generally fractured aquifer at the site rather than one where flow is dominated by one or more major fractures or faults, i.e. groundwater flow will be pseudo-radial at the local and regional scale. Another key factor is that the main aquifer that will impact on dewatering and groundwater control measures or be impacted on by contamination will be the intergranular Sandveld Aquifer. For detailed modelling at the dewatering design stage, features such as dykes and their possible impact on flow will need to be further investigated.

Scenario 1 and 2: Dewatering of Nuclear Installation Foundations (average rainfall and high rainfall per scenario, respectively)

The Nuclear-1 installation(s) will be founded in Malmesbury bedrock, as per the KNPS, necessitating excavation into the largely unconsolidated Sandveld Aquifer sediments and down to unweathered bedrock. The Sandveld Aquifer has a shallow water table and pre-dewatering will be required for successful and safe excavation of foundations.

In model scenarios 1 and 2, the Nuclear-1 excavation area is fully dewatered, with excavations assumed to be down to bedrock. Scenario 1a (Sc1a) assumes that there is no cut-off wall, whereas scenario 1b (Sc1b) includes the assumption of a bentonite-cement cut-off wall surrounding the excavation area. Both scenarios assume average rainfall. The resultant zone of drawdowns for Sc1a and Sc1b are shown in ***Drawing 5.11.12*** and ***Drawing 5.11.13***, respectively.

Scenarios 2a and 2b (Sc2a and Sc2b) are the equivalent scenarios to Sc1a and Sc1b in terms of dewatering and cut-off wall, but assume high rainfall for the two years of dewatering. The high rainfall assumed is *c*.623 mm/a, calculated as a 1:100 year event, as described in the model assumptions.

The expected volumes of groundwater that will be generated are shown in ***Table 5.11.32***.

Table 5.11.32
Predicted Dewatering Inflows

Climate Change	**Normal Dewatering (ℓ/s)**	**Dewatering with Cut-off Wall (ℓ/s)**
Current Average Conditions (Sc1a and Sc1b)	32	20
1:100 Year High Rainfall Conditions (Sc2a and Sc2b)	43	27

Figure 5.11.24 shows the potential variance in inflow rates due to long-term average seasonal changes in rainfall. Dewatering with current average rainfall conditions, excluding the cut-off wall, is shown by the Scenario 1a (Sc1a) solid blue line. This is considered to be the most likely scenario. Sc1a (orange solid) includes the cut-off wall. Dashed lines (Sc2a and Sc2b) assume high rainfall for the two years of dewatering and thus represent a worst-case maximum inflow.

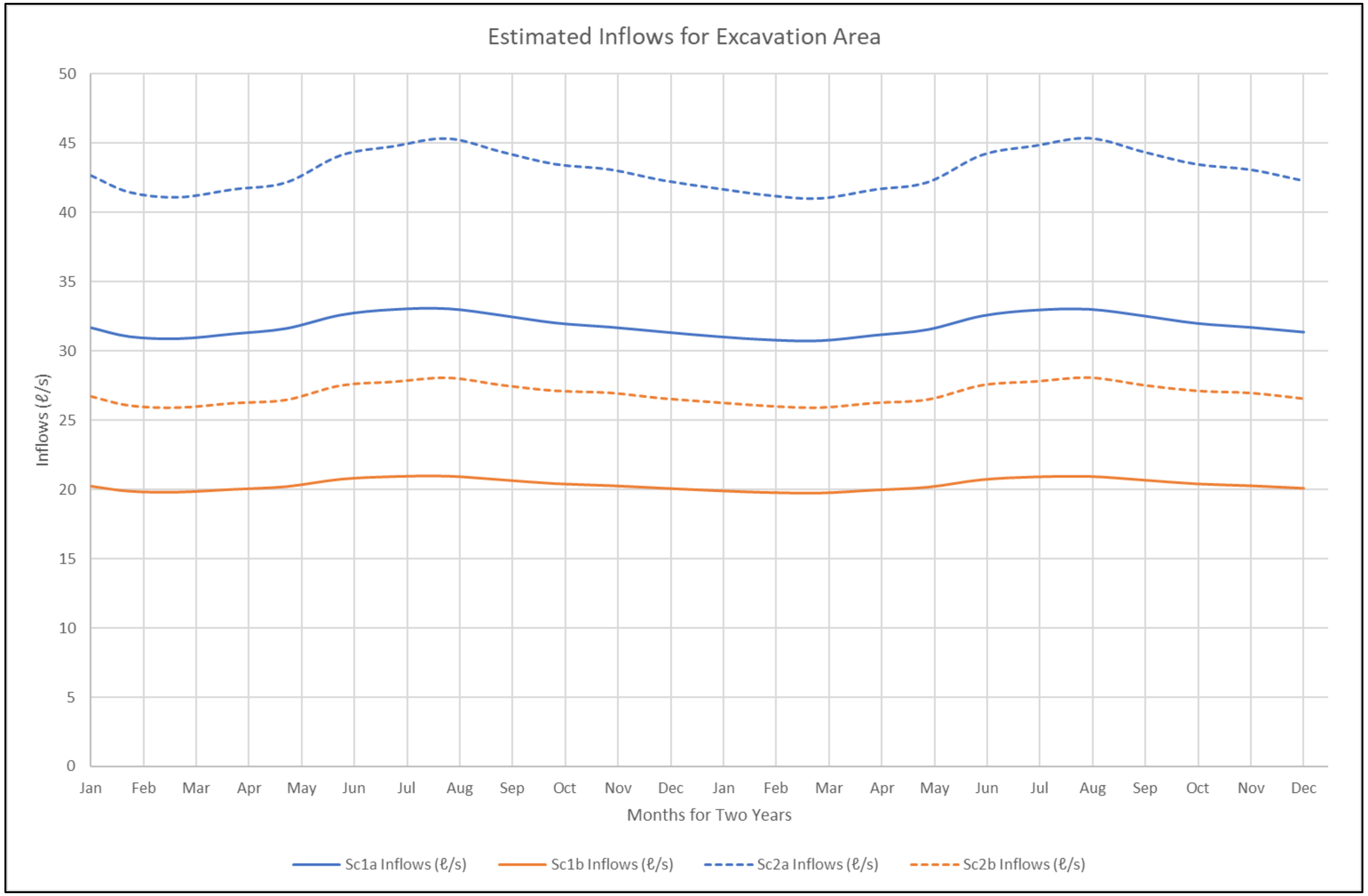
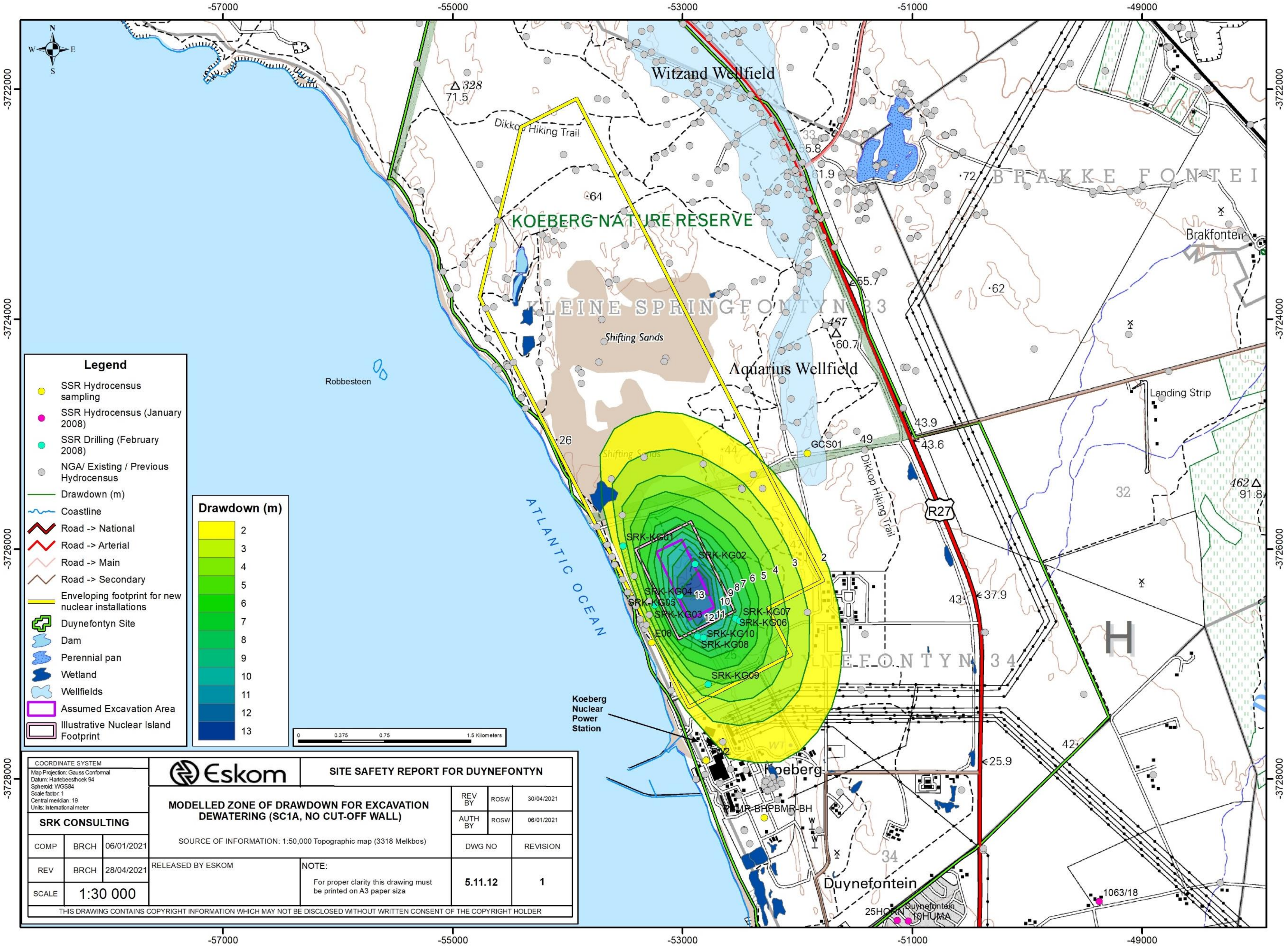


Figure 5.11.24
Estimated Inflows for Excavation Area

The estimated water inflows for the excavation area will be intercepted by boreholes and wellpoints and can thus be used to augment water supply to the site during construction.

By including a cut-off wall, the maximum inflow is reduced from 32 ℓ/s to 20 ℓ/s under normal conditions. The zone of drawdown is also reduced from 3 200 m (parallel to the coast) by 1 600 m (perpendicular to the coast) down to 2 000 m (parallel to the coast) by 1 100 m (perpendicular to the coast), as can be seen in ***Drawing 5.11.13***. The inclusion of a cut-off wall is recommended as the final location of the nuclear terrace has not been decided and this design will provide the most protection to the nuclear installation foundations. This method of groundwater control was successfully used during excavation for the foundations of the KNPS and a pumping rate of 21 ℓ/s was required to dewater the excavation (Eskom, 2006), very similar to that predicted by the current model. This gives further confidence in the modelled scenarios presented here.

A system of cut-off walls, boreholes and wellpoints was successfully used for dewatering/groundwater control for the excavation for the KNPS **(Brink, 1981)**. This enabled the bedrock surface exposed in the base of the excavation to be mapped for geotechnical engineering purposes and for the foundations to be laid safely and in dry conditions. The time taken for full excavation of the KNPS site was 5.5 months **(Brink, 1981)**.



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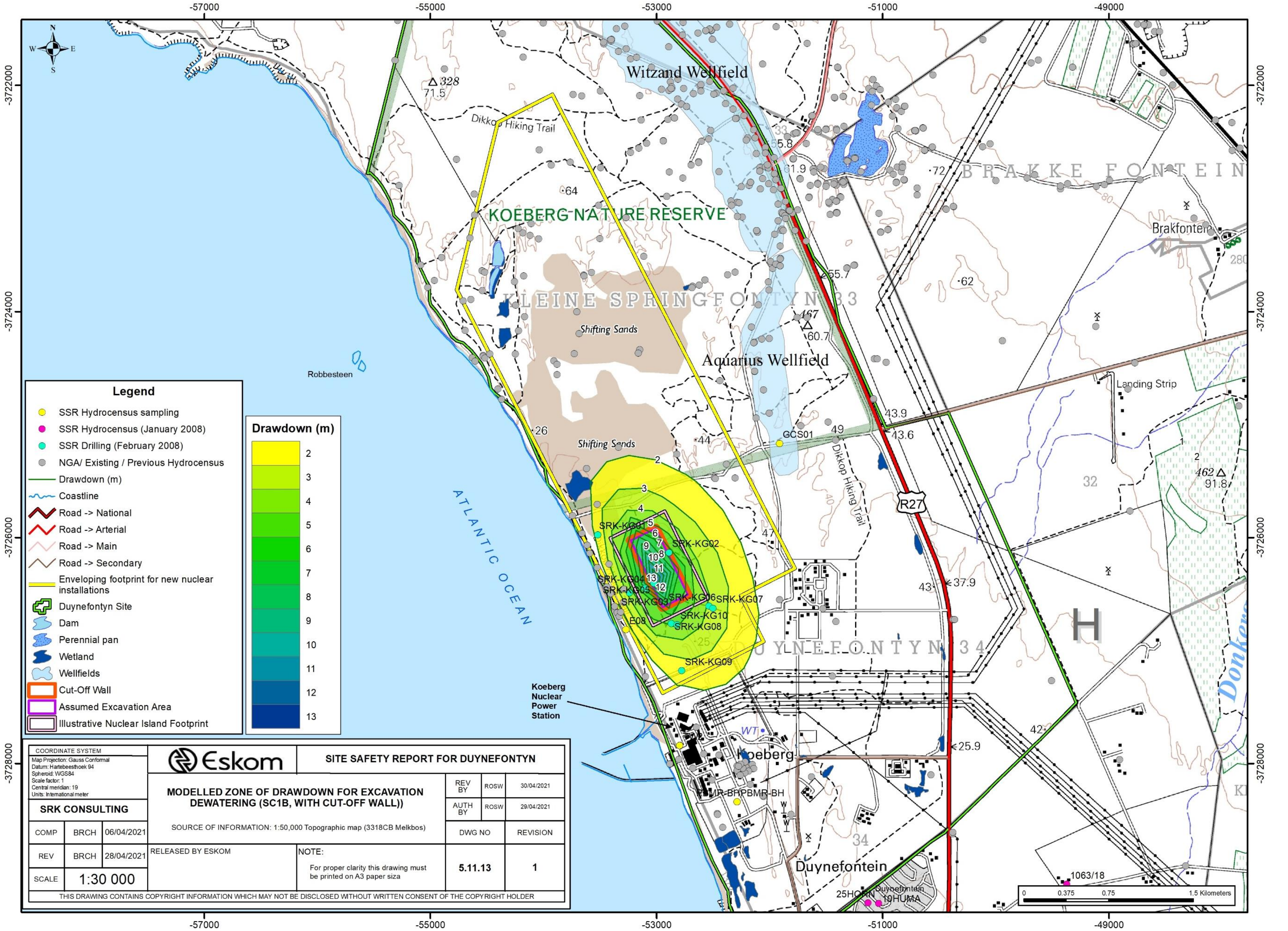

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Scenario 3: Impact of Increase in Sea Level on the Groundwater System and Flooding Risk

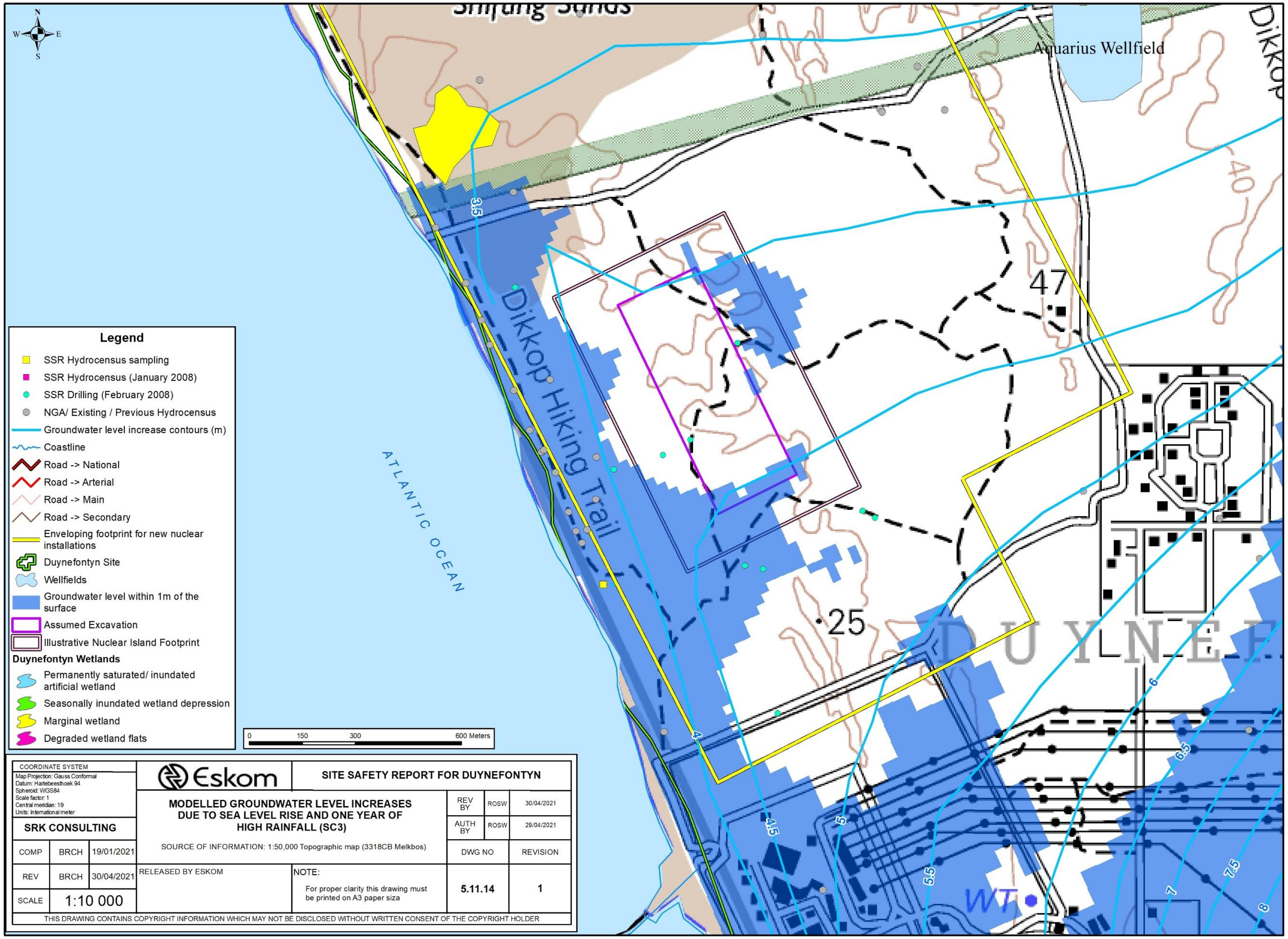
The results of the model scenario 3 (Sc3), which assumes long-term steady state sea level rise (to 2.3 m) and one year of high rainfall (of *c*.1 498 mm/a, based on the 1:10^8 year probability) as described in the assumptions, indicates that groundwater levels at the site could rise 4 to 5 m above current levels, as shown by the contours in ***Drawing 5.11.14***. As indicated by the blue shaded areas, this brings the groundwater in many of the lower-lying parts of the site to within 1 m of ground surface, thus increasing the potential for local flooding. However, it is assumed that the nuclear terrace will be raised above the natural ground level to safeguard against such flooding and, *inter alia*, flooding by tsunamis, storm surges and abnormally high tides.

Scenario 4: Groundwater as a Potential Source of Water

Groundwater available from dewatering of the excavation area under 2020 conditions (discussed in scenario 1) is potentially *c*.20 ℓ/s with a cut-off wall, rising to 27 ℓ/s under high rainfall conditions. In addition, scenario 4 assumes pumping from the Aquarius Wellfield at the sustainable rates calculated by Advision (*op cit*) and shown in ***Table 5.11.11***, totalling 29.5 ℓ/s across eight boreholes. Three scenarios were run under varying rainfall conditions, as per the model assumptions:

- Sc4a: average rainfall (Koeberg MAP of 372 mm/a);
- Sc4b: wet / high rainfall conditions (1:100 year MAP of *c*.623 mm/a) for both years of wellfield pumping;
- Sc4c: drought / low rainfall conditions (equivalent to the 2015 MAP of *c*.218 mm/a) for both years of wellfield pumping.

The full 29.5 ℓ/s was sustained for all three scenarios, without any of the boreholes ‘running dry’. The drawdown associated with the Aquarius Wellfield pumping after two years for drought rainfall conditions (Sc4c) is shown in ***Drawing 5.11.15***. The maximum drawdown is *c*.14 m and the drawdown zone extends by *c*.2 700 m north-south and *c*.2 200 m east-west. Note that although Sc4 includes simultaneous wellfield pumping, along with drawdown due to dewatering of the Nuclear- 1 foundation excavation, the drawdown zone shown on ***Drawing*** 5.11.15 is only that which directly results from wellfield pumping. The interference drawdown from the dewatering was removed from the model results so that the drawdown from wellfield pumping could be assessed individually. The removal of the interference from excavation dewatering altered the maximum drawdown within the wellfield by <1 m. However, it is likely that desalination of seawater will be the preferred option for freshwater supply to the site and this is discussed in detail in ***Section 5.12*** (water use licence applications for the above activities are beyond the scope of this SSR).



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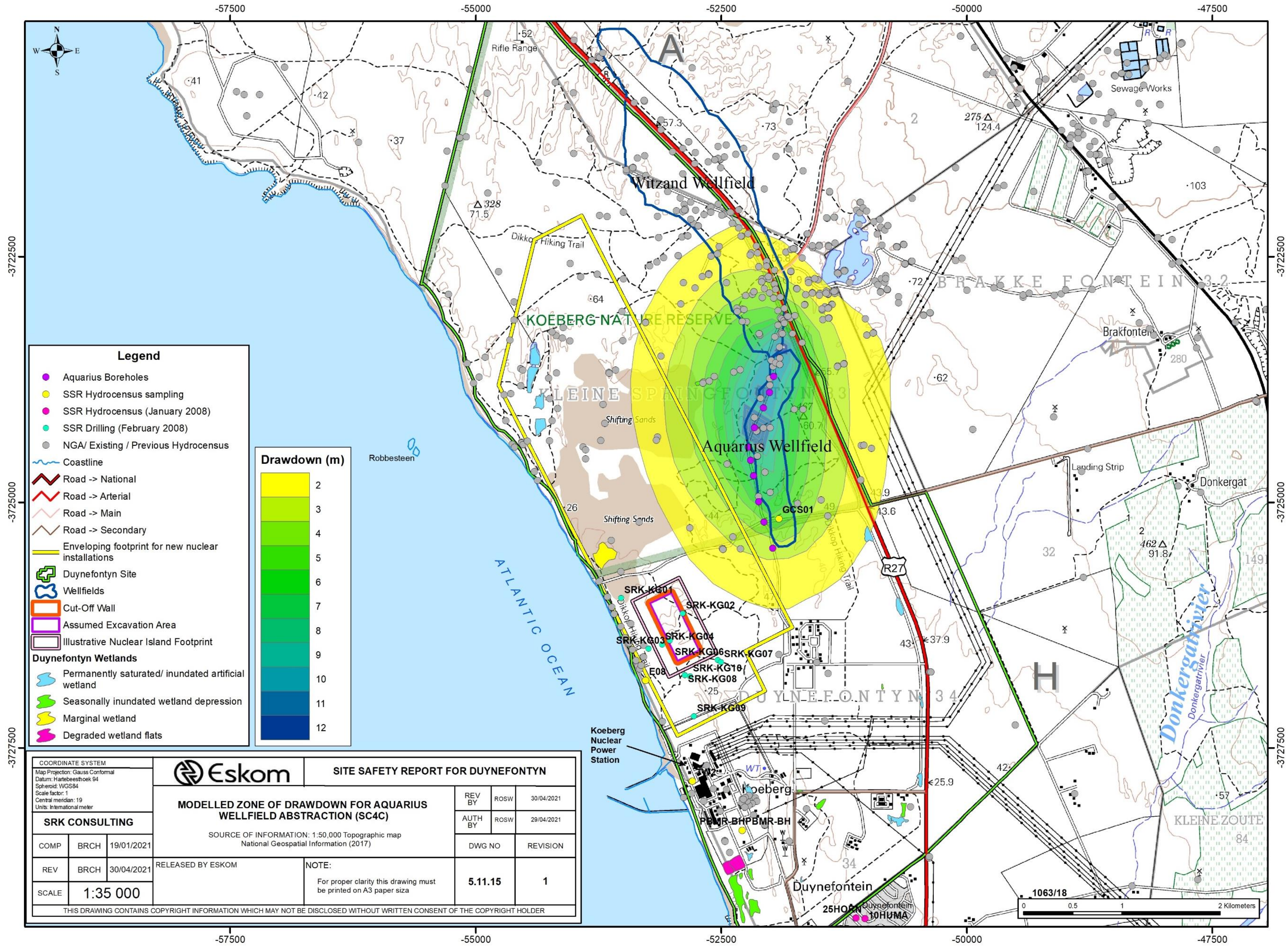

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Scenario 5: Seawater Intrusion

In this scenario the potential of induced seawater intrusion is investigated under the influence of dewatering of foundations. EC was used as the indicator element, with seawater assumed to have an EC of 5 000 mS/m. Density dependency was included in the modelling, which was undertaken within the *Modflow-USG Transport* software. Three scenarios were run under varying conditions, as follows:

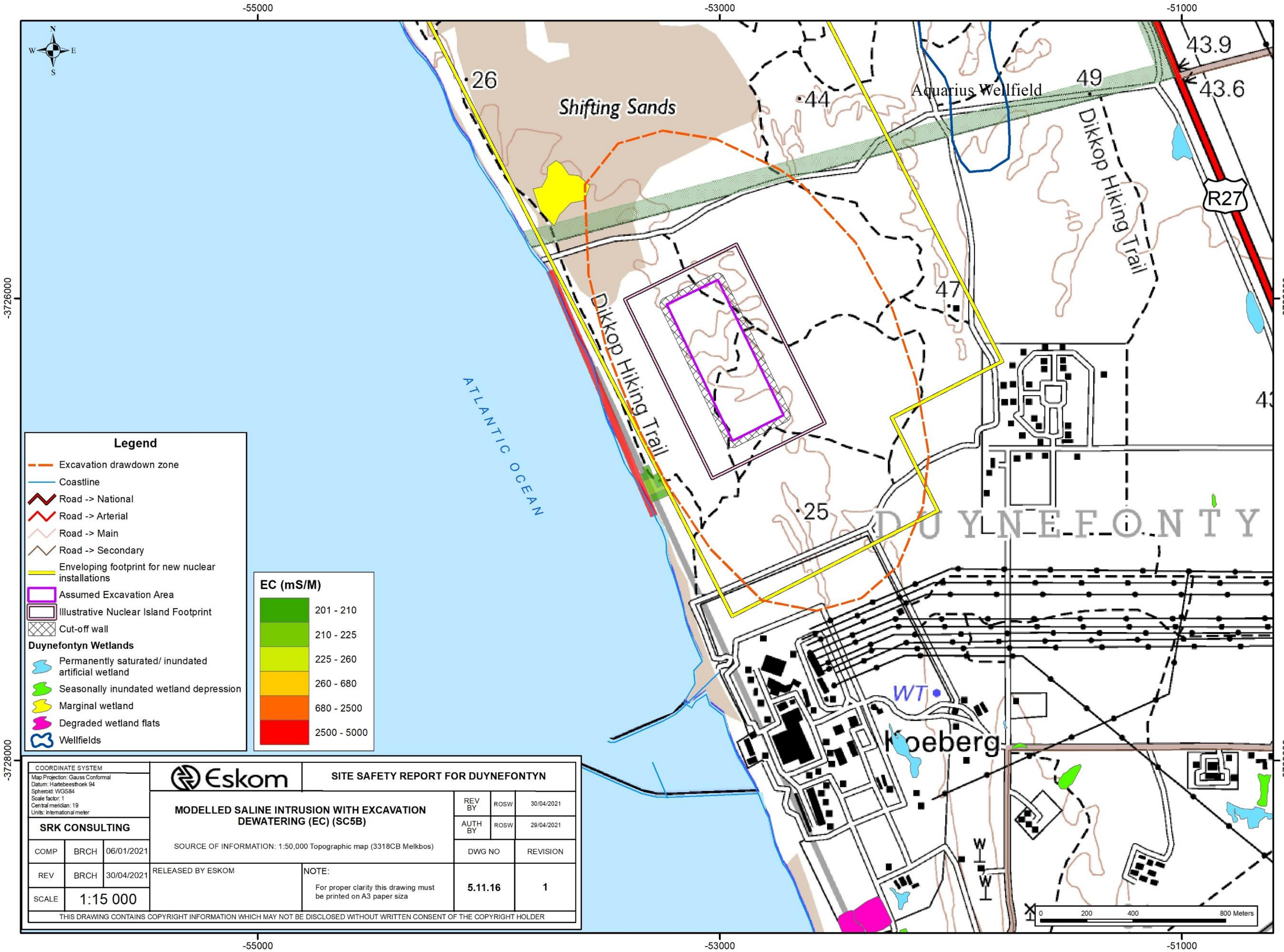
- Sc5a: baseline (natural) seawater intrusion;
- Sc5b: seawater intrusion with the dewatering of the excavation area for two years, with the use of a cut-off wall, without the effects of climate change;
- Sc5c: seawater intrusion with the dewatering of the excavation area for two years, with the use of a cut-off wall, including the effects of sea level rise due to climate change.

The scenario results for potential seawater intrusion during the dewatering of the excavation area is shown in ***Drawing 5.11.16*** and ***Drawing 5.11.17*** for conditions excluding and including sea level rise, respectively.

Seawater intrusion extends up to *c*.100 m inland directly downgradient of the excavation site under current climatic conditions. With climate change considerations of sea level rise, local seawater intrusion may extend up to *c*.400 m inland.

Any saline intrusion should reverse with time once the temporary dewatering measures are deactivated after casting of foundations.

Groundwater chemistry was monitored during construction of the KNPS units 1 and 2 to observe possible ingress of seawater (Eskom, 2006). However, an increase in groundwater salinity, presumably due to seawater ingress, was only noted in one monitoring borehole in the fractured rock aquifer, where SO_4 concentrations increased from 40 to >400 mg/ℓ during dewatering. There was no measurable effect on groundwater quality in the upper Sandveld Aquifer. This appears to indicate that installation of a cut-off wall is/will be effective in limiting the effects of dewatering/groundwater control around the nuclear installation excavations at the site. Seawater intrusion in the Malmesbury Aquifer will likely be localised along individual fractures and, based on the KNPS experience, will not pose a safety hazard. The KNPS is also located closer to the coast than the illustrative footprint for Nuclear-1.



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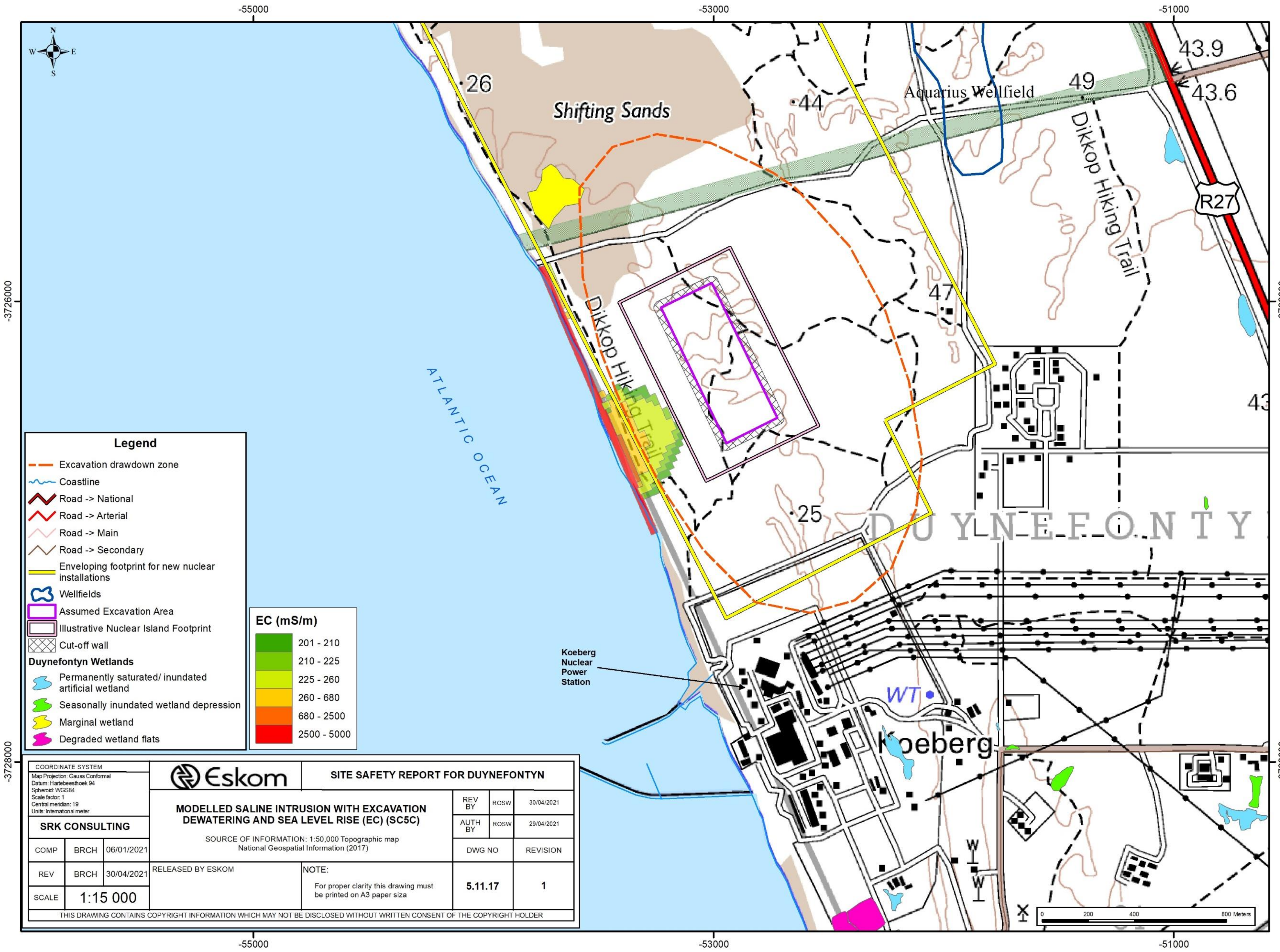

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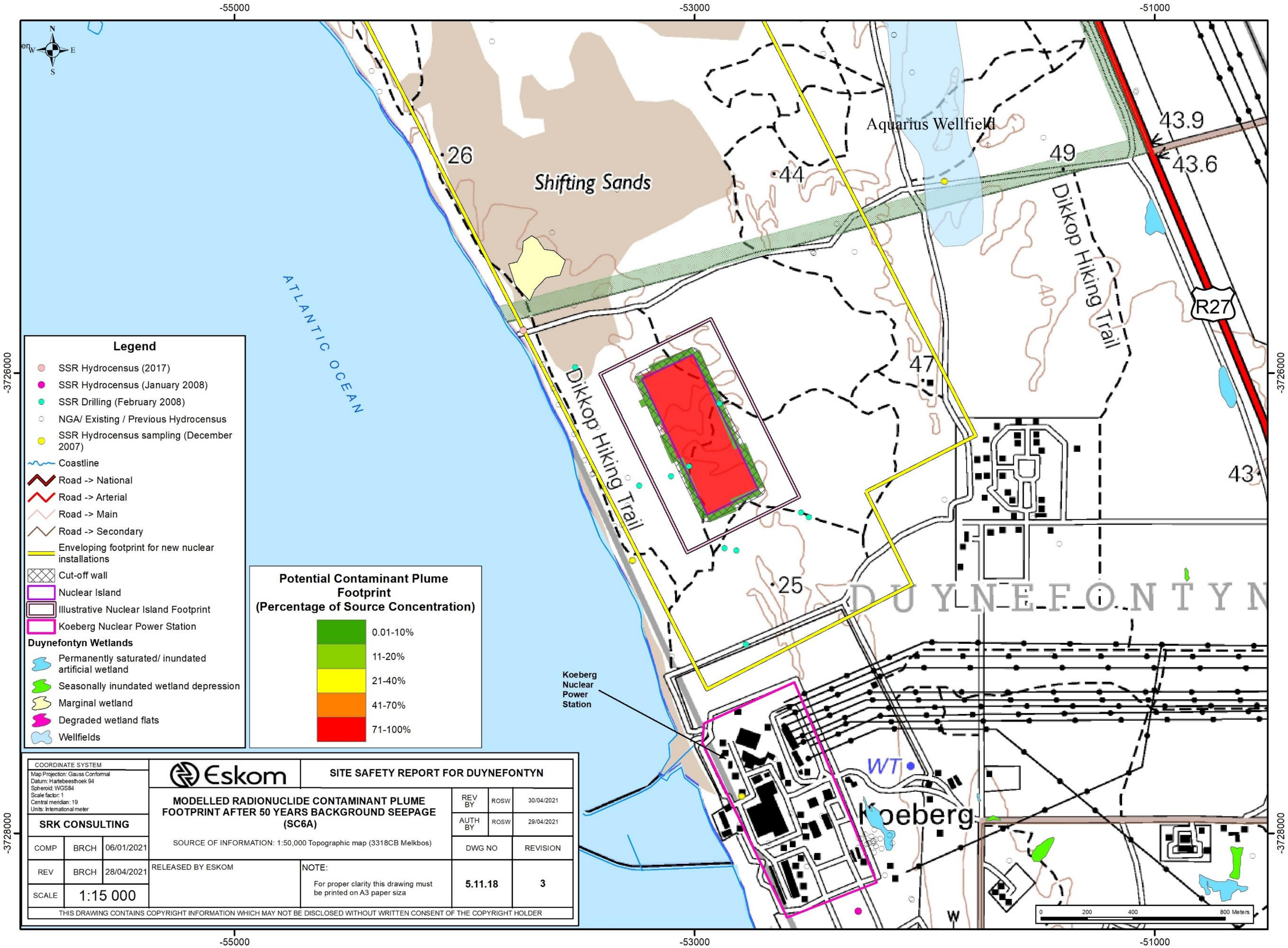
Scenario 6: Transport of Radionuclides

This scenario assesses the potential transport of contamination/ radionuclides from the Nuclear-1 island in groundwater, should there be a liquid leak from the site. The assumptions used were as follows:

- A surrogate contaminant was assumed at 100 per cent concentration at the footprint.
- A retardation factor, K_d, equivalent to that derived from laboratory tests for Sr-90 (1.18 mℓ/g) was assumed.
- Scenario 6a (Sc6a) assumes contamination over the whole footprint for 50 years.
- Scenario 6b (Sc6b) assumes a localised leak for one month at the northeastern corner of the footprint and two years for spreading.
- Scenario 6c (Sc6c) assumes a localised leak for one month at the northeastern corner of the footprint and spreading for 50 years.

The potential groundwater contamination plume for Sc6a, Sc6b and Sc6c are shown in ***Drawing 5.11.18***, ***Drawing 5.11.19*** and ***Drawing 5.11.20***, respectively.

In all three scenarios, contaminant migration is minimal and confined to the illustrative Nuclear-1 footprint. There is no impact on any surrounding installations such as the Aquarius Wellfield.



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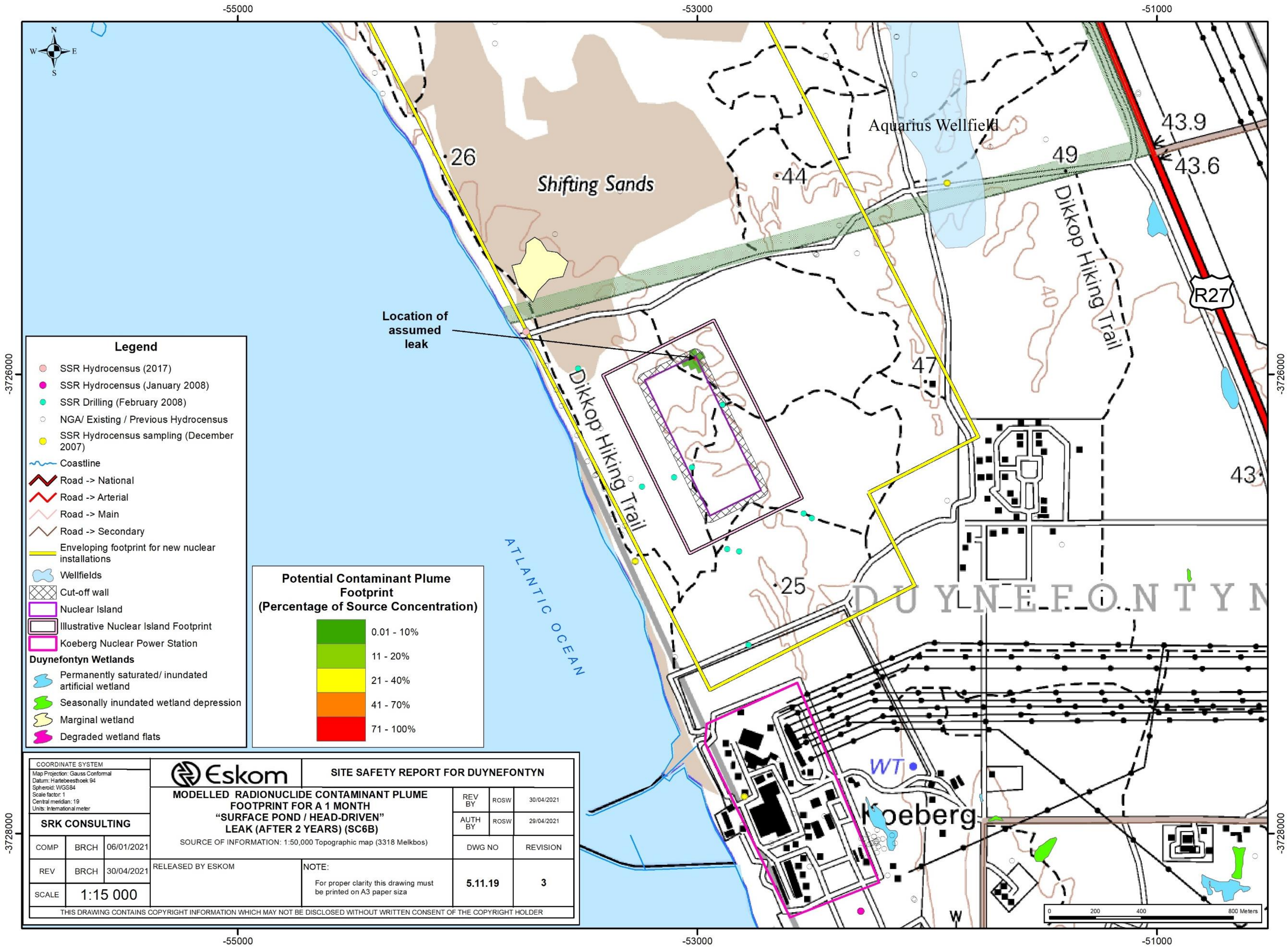

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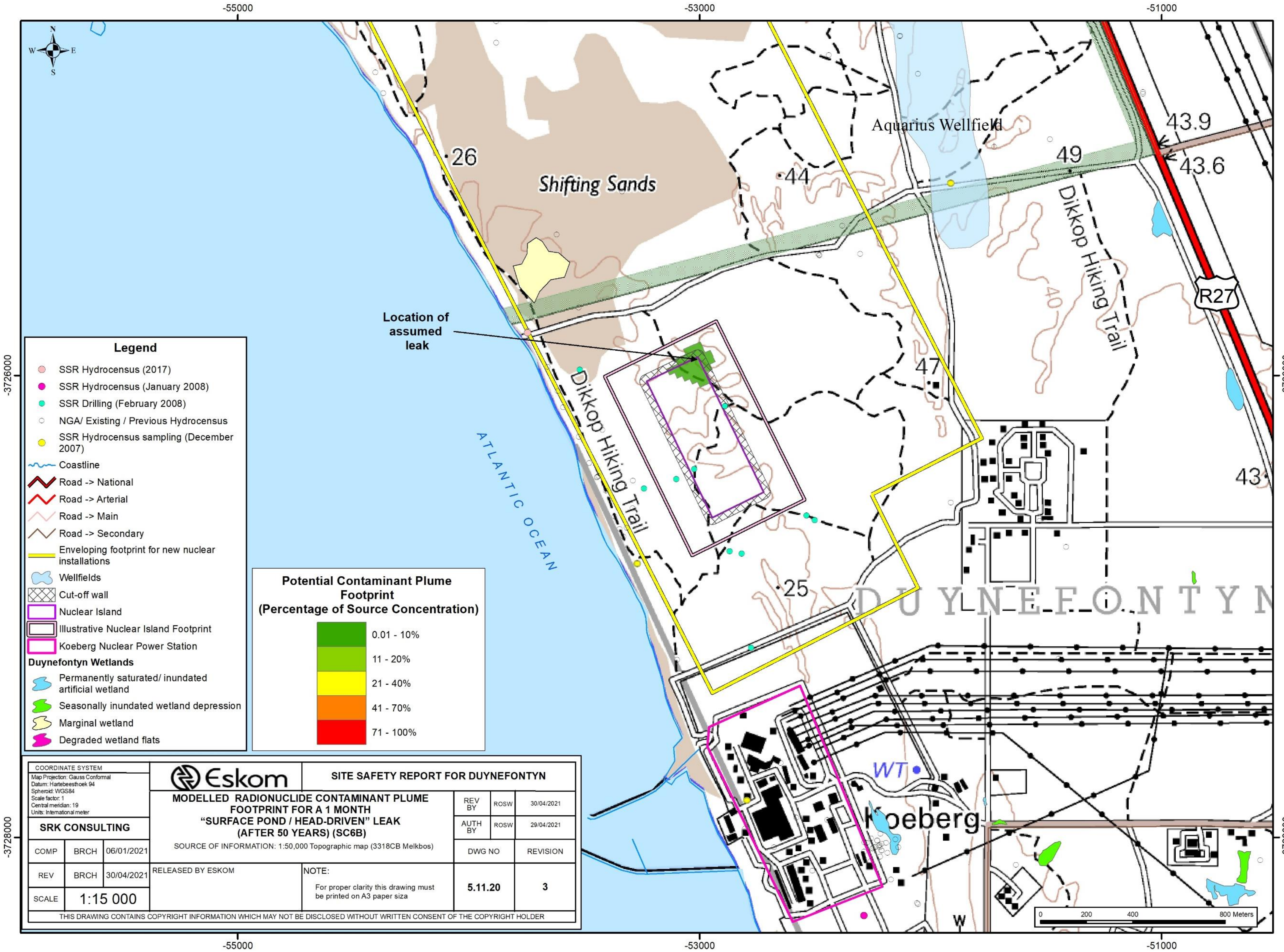

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5.11.8 Monitoring

Seven monitoring boreholes and three piezometers are located around the two reactors at the KNPS. These boreholes are presently solely used for groundwater monitoring purposes (Council for Scientific and Industrial Research, 2007a), (Council for Scientific and Industrial Research, 2007b), (Council for Scientific and Industrial Research, 2019) and (Bugan & Tredoux, 2019). A further six monitoring boreholes were also drilled at the planned PBMR DPP site (PBMR1 to PBMR6) to monitor groundwater levels, macro chemistry and H-3 concentrations in both the primary aquifer and the underlying Malmesbury Aquifer (SRK Consulting, 2010). This monitoring programme commenced during February 2008 (SRK Consulting, 2010), but was terminated in mid-2010 due to cancellation of the PBMR DPP project. The investigation of the site and the understanding gained of its geohydrological characteristics was supported by the establishment of a representative monitoring network to cover the two main aquifers present, i.e. the Sandveld and Malmesbury aquifers. Meteorological monitoring was carried out via the KNPS meteorological station and a new meteorological monitoring station (see ***Section 5.8***). The groundwater monitoring network was established in mid-2008 with the purpose of determining baseline groundwater levels and quality and ranges in values thereof, viz:

- **groundwater levels** – establishing seasonal trends and response to extreme weather conditions, i.e. high rainfall events and droughts, as previously defined;
- **wetlands** – determination of interaction with groundwater;
- **groundwater quality** – analysis of samples for selected radionuclides, macro-groundwater quality and trace elements, as described in more detail below.

The monitoring network (see ***Drawing 5.11.21***) comprises of:

- one Sandveld Aquifer borehole (SRK-KG10) and one Malmesbury Aquifer borehole (SRK-KG3) at or near the illustrative footprint, equipped with automatic water level/temperature recorders (data loggers);
- a barometric logger in SRK-KG3 to record the barometric pressure variation in order to correct the water level data;
- two Sandveld Aquifer boreholes with one (G33444) near the Aquarius Wellfield and one (D-SW7-MR3) near the CoCT's Witzand Wellfield;
- six boreholes (SRK-KG1, KG2, KG4, KG6, KG8 and KG9), located at or near the illustrative footprint, monitored on a six-monthly basis (May and

November) - The first monitoring run was conducted during May 2008 but this programme was halted after the May 2009 sampling as sufficient data had been collected for SSR requirements (see last bullet point below).

- seven boreholes (PBMR1-11a, 11b-12, PBMR2, PBMR3, PBMR4, PBMR5 and PBMR6), seven piezometers (P1, P2a, P2b, P4, P5, P6 and P7) and six surface water monitoring water points (SW1-6) are located at the PBMR DPP site - Boreholes PBMR1-6 were sampled and monitored on a monthly basis from February 2008 but the programme was terminated in mid-2010 with cancellation of the PBMR project. The monitored boreholes were sampled for the same chemical and stable isotope determinands as listed below (National Nuclear Regulator, 2016).

- samples taken for macro- and micro-chemical, stable isotope and selected radionuclide analysis - Analyses include cations (Na, K, Ca, Mg, NH_4) and anions (Cl, SO_4, NO_3, NH_3, PO_4, HCO_3), metals (Fe, Mn), trace elements (F), radionuclides (U, Th, Ra, gross α and β activity), isotopes (D/H-1, O-18/O-16, H-3), pH and EC.

- three additional boreholes and three piezometers installed in and surrounding the defined wetlands within the illustrative footprint area in February 2010 for more detailed monitoring purposes. These boreholes and piezometers are being used to monitor the wetland water levels and determine the surface/wetland water chemistry (as per the above chemical and isotope list) and the relationship between the surface water/wetland and the groundwater.

The monitoring programme was further upgraded in early 2011, to cover all pre-construction monitoring requirements, i.e. SSR, EIA and wetlands, with two additional data loggers being deployed (G33444 and D/WP3) and bi-annual manual water level measurements and water quality sampling (SRK Consulting (South Africa) Pty Ltd, 2020) and (SRK Consulting and Freshwater Consulting Group, 2011). Monthly, quarterly and annual reports were produced by the SSR geohydrological consultants up to the end of 2013.

On the basis of the results to date and this SSR developed for the site, additional monitoring points may be established to provide a more extensive network and confirmation of the site parameters prior to construction activities. This network will take into account the exact location of the nuclear terrace. Results up to October 2020 (January 2021 for logger equipped boreholes) have been described in previous subsections and show no anomalous or concerning trends related to climatic extremes and potential impact on nuclear power station site safety.

Monitoring reports will be used in the regular update of the SSR. The monitoring reports that are gathered over the life of the nuclear site and used in the development and update of this SSR will be stored in the Nuclear Sites archive and will be available to the regulator on request. Where monitoring results may alter the design bases of the site, their implications will be evaluated and communicated to the NNR, either as part of an updated SSR or as a freestanding report.

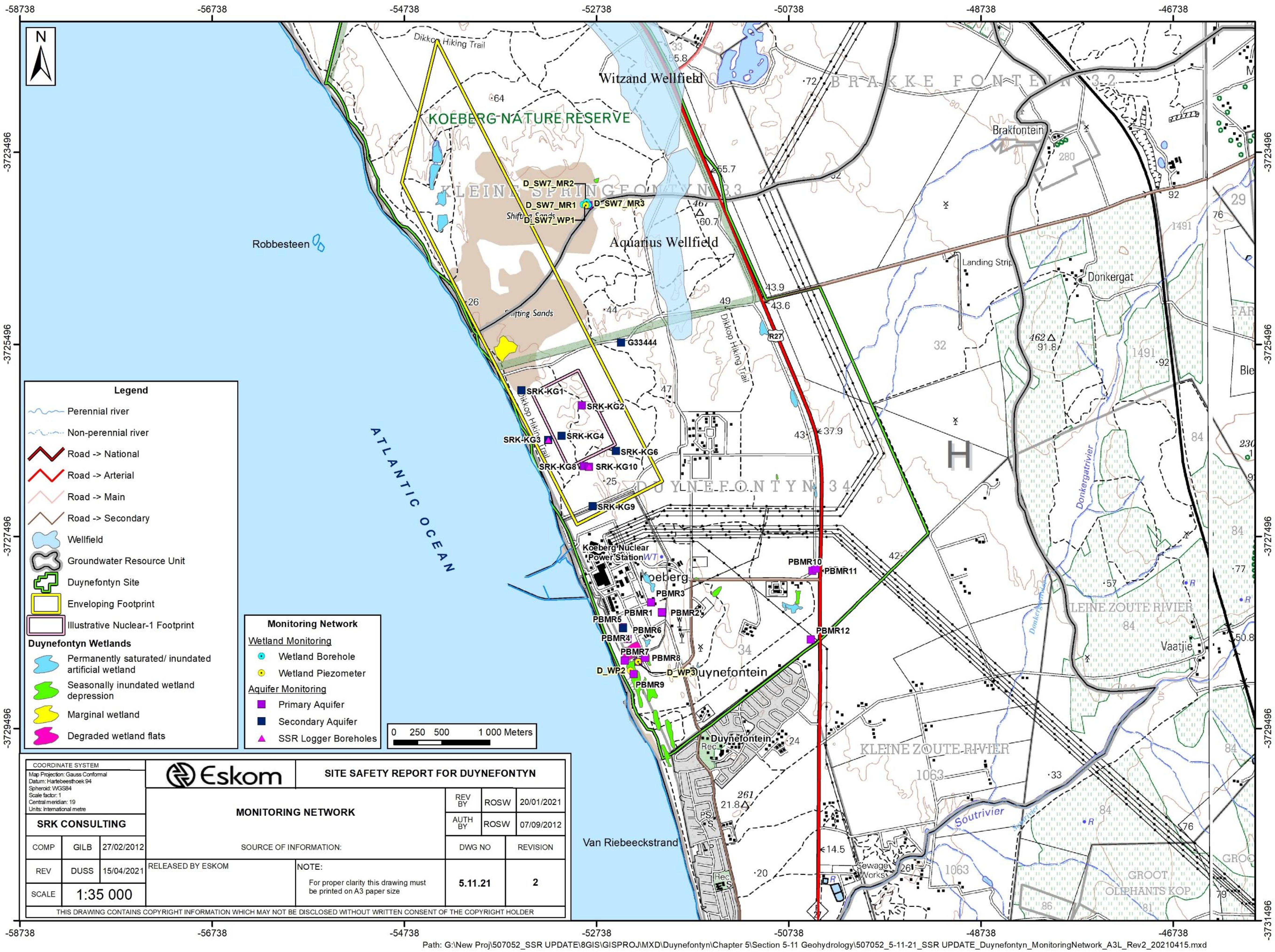
5.11.9 Management of Uncertainties

Uncertainties in terms of geohydrology of the site and impacts on safety of nuclear installation(s) constructed at the site mainly centre around inherent uncertainties in deriving geohydrological parameters for the Earth's subsurface, groundwater level fluctuations in terms of extreme rainfall events and sea level rise due to global warming. In terms of geohydrology, these uncertainties are managed and minimised at the site by:

- carrying out multiple tests and analyses;
- long-term (13 years for SSR monitoring stations; longer for non-SSR stations) measurement of groundwater levels and precipitation;
- comparing results to actual measurements during construction of the KNPS, other similar areas and published data;
- applying the experience of the project geohydrologists and peer reviewers;
- numerical model calibration, sensitivity analysis and V&V, plus additional data collection and more detailed modelling at the design stage and later stages of site development;
- applying 'worst-case' parameters to scenarios such as sea level rise and contaminant transport;
- applying the worst-case scenario of annual rainfall for a 10^{-8} event as derived from ***Sections 5.8*** and ***5.10***.

In terms of nuclear installation safety, long-term monitoring is being carried out to build up a time series record of fluctuations in measurable parameters. The wealth of data available from studies of the nearby Atlantis Aquifer and construction and operation of the KNPS over the past 35 years also provide a high level of assurance that uncertainties are minimised and do not pose a safety threat to the existing and proposed nuclear installation(s).

The above measures have all been applied to the evaluation of the geohydrology of the site for this SSR. The analyses and inferences drawn in this section on geohydrology are therefore considered to be realistic and present a sufficient level of confidence for the purpose of this SSR. The SSR monitoring record covers wet and severe drought periods and the groundwater level responses recorded indicate that the aquifer(s) have a sufficient buffering capability to absorb such events with insignificant fluctuations in groundwater levels.



Legend
Perennial river
Non-perennial river
Road -> National
Road -> Arterial
Road -> Main
Road -> Secondary
Wellfield
Groundwater Resource Unit
Duynefontyn Site
Enveloping Footprint
Illustrative Nuclear-1 Footprint
Duynefontyn Wetlands
Permanently saturated/ inundated artificial wetland
Seasonally inundated wetland depression
Marginal wetland
Degraded wetland flats
Monitoring Network
Wetland Monitoring
Wetland Borehole
Wetland Piezometer
Aquifer Monitoring
Primary Aquifer
Secondary Aquifer
SSR Logger Boreholes
0 250 500 1 000 Meters
ATLANTIC OCEAN
KOEBERG NATURE RESERVE
Witzand Wellfield
Aquarius Wellfield
Robbesteen
Koeberg Nuclear Power Station
Koeberg
Duynefontein
Van Riebeeckstrand
Brakfontein
Donkergat
Vaatjie
Soutrivier
Donkergatrivier
KLEINE ZOUTE RIVIER
GROOT OLIPHANTS KOP
D_SW7_MR2
D_SW7_MR1
D_SW7_MR3
D_SW7_WP1
G33444
SRK-KG1
SRK-KG2
SRK-KG3
SRK-KG4
SRK-KG6
SRK-KG8
SRK-KG10
SRK-KG9
PBMR10
PBMR11
PBMR3
PBMR1
PBMR2
PBMR5
PBMR6
PBMR4
PBMR7
PBMR8
D_WP2
D_WP3
PBMR9
PBMR12
COORDINATE SYSTEM
Map Projection: Gauss Conformal
Datum: Hartebeesthoek 94
Spheroid: WGS84
Scale factor: 1
Central meridian: 19
Units: International metre
SRK CONSULTING
Eskom
SITE SAFETY REPORT FOR DUYNEFONTYN
MONITORING NETWORK
REV BY ROSW 20/01/2021
AUTH BY ROSW 07/09/2012
COMP GILB 27/02/2012
REV DUSS 15/04/2021
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SOURCE OF INFORMATION:
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5.11.10 Management System

The geohydrological investigations performed for this SSR entailed the following:

- desk study;
- site investigation;
- data analysis and reporting;
- use of computer software codes for interpretative and predictive modelling;
- monitoring.

The main sources of information used in compilation of this section are referenced in the text and listed under ***Subsection 5.11.12***.

All site work was carried out with reference to a quality data pack, which includes, *inter alia*, SRK's Integrated Quality Management System, Project Quality Plan, Method Statement, Quality Control Plan, Health, Safety and Environmental Management Plan, Risk Assessment, Monitoring Plan, Monitoring Team Quality Audits, Monthly Monitoring Reports, Annual Monitoring Reports and Duplicate Samples for Laboratory Quality Control. This information is included in ***Appendix 5.11.K***. Details on borehole site selection, drilling methodologies and other site investigation approach details are mainly contained in the appendices and are not discussed in the main body of this SSR, to facilitate ease of reading.

A quality assurance programme was established to control the effectiveness of the execution of these investigations, the data analysis and the formulation of conclusions on the site acceptability. This conforms to the overall management system for the SSR, which is described in detail in ***Chapter 10***, which covers *inter alia* NNR regulations, international guidelines (***Subsection 5.11.3***) and relevant classification procedures. The geohydrological evaluation of the site has been determined as Safety Class C, i.e. not important to nuclear safety, and in terms of the procedure, compliance with an ISO 9001 or equivalent system was implemented (Eskom, 2009) and (National Nuclear Regulator, 2016).

The activities carried out as part of the evaluation of the site and the results achieved are presented in detail in appendices to this section. These appendices provide the quality assurance records for key decisions and methodologies used and provide the back-up for the data presented in this section. They present a clear and auditable trail showing how key decisions were made and conclusions reached. The information presented in the appendices includes:

- ***Appendix 5.11.A*** – Historical borehole data.
- ***Appendix 5.11.B*** – Hydrocensus data.
- ***Appendix 5.11.C*** - Geophysical data and graphs and borehole site selection criteria.
- ***Appendix 5.11.D*** - Exploration borehole logs.
- ***Appendix 5.11.E*** - Yield testing, down-hole video camera surveying, down-hole EC-pH-Temp logging and packer testing data files and analyses.
- ***Appendix 5.11.F, G & H*** – Laboratory analytical results for hydrocensus, drilling and monitoring, i.e., macro-chemistry, radionuclides and isotopes as well as monitoring data for field water quality measurements and water levels.
- ***Appendix 5.11.I*** – Adsorption testing report.
- ***Appendix 5.11.J*** – Numerical model specialist report and V&V assessment, including sensitivity analysis.
- ***Appendix 5.11.K*** – Quality data pack including a detailed process map containing references to the various data files, plus:
  - SRK's integrated quality management system;
  - Project Quality Plan;
  - Method Statement;
  - Quality Control Plans;
  - Risk Assessment (for site activities);
  - Health, Safety and Environmental Management Plan;
  - Peer review reports;
  - Monitoring reports;
  - Monitoring Database;
  - Duplicate sample laboratory quality control reports;
  - Laboratory analysis reports;
  - Quality audit reports on monitoring team activities;

- calibration sheets for field equipment such as pH/EC and dip meters (GPS did not require calibration as it contained no internal compass);
- list of approved suppliers used;
- sign-off sheet for borehole sites.

The characterisation of geohydrological site parameters and their evaluation do not lend themselves to direct verification by inspections or tests that can be precisely defined and controlled and therefore a peer review process must be followed. This was carried out by suitably qualified, independent and experienced professionals.

Electronic records have been stored in a secure central repository with regular off-site back-up procedures. The overall quality management system complied with that set out in ***Chapter 10*** of this SSR. All references cited are saved in the central repository.

The activities that have been carried out with their respective links to other SSR sections/chapters and quality control requirements are presented in ***Table 5.11.33***.

Table 5.11.33
Summary of Activities, Links and Quality Requirements

Activity	Links		Quality Requirements
	Inputs	Outputs	
Hydrocensus	DHSWS NGA Existing reports	***Section 5.5;*** ***Section 5.10***; ***Section 5.12***. Information on existing groundwater use from boreholes and springs will provide essential input into the Land Use, Hydrology and Water Supply (***Sections 5.5. 5.10*** and ***5.12***), mainly on quantities used and quality.	Calibration of field equipment, e.g. pH, EC and dip meters.
Geophysics	***Section 5.13*** and ***5.15***	***Sections 5.13***; ***5.14*** and ***5.15***. Interpretation of the geophysical surveys will provide key input to geotechnics, geology and seismics regarding concealed structures and lithologies	Method Statement
Borehole Siting	***Sections 5.13***; ***5.14***; and ***5.15***. Discussion with the geotechnical, geology and seismic teams and Eskom to optimise on siting and use of boreholes. Use of modelling where appropriate.		Table showing rationale for number, position, aquifer, depth, construction. Peer Review

Activity	Links		Quality Requirements
	Inputs	**Outputs**	
Drilling/Testing		***Sections 5.13***; ***5.14***; and ***5.15***. ***Chapter 11***. Lithological logs and other geological and hydrogeological information will be used as key input into the geotechnical, geology and seismics sections.	Use of approved suppliers. Rationale for drilling methods used. Risk assessment. Method Statement. Health, Safety and Environmental Management Plan. Peer Review. Adherence to contract specifications regarding recording of data, sampling, borehole completion, verticality and alignment. Appropriate ISO standards.
Laboratory Analysis		***Sections 5.5***; ***5.10***; ***5.12***. Water quality data will be used as input to the Land Use, Hydrology and Fresh Water Supply sections	Use of approved suppliers. Certificate of accreditation for selected laboratories. (SABS code 0259 or equivalent international standard)
Modelling	***Section 5.8.*** Definition of wet and dry/drought periods and probabilistic estimates of extreme rainfall.	***Section 5.12***: ***Chapters 7*** and ***11***	Table showing rationale for selection of model code(s). International benchmarking, use and acceptability. Validation and verification of computer software codes used to comply with NNR requirements. Uncertainties and management/incorporation thereof. Sensitivity analysis. Peer Review
Monitoring		***Section 5.2***	Method statement

A regulatory compliance table is listed in ***Table 5.11.34*** to indicate where the relevant legal and regulatory issues have been dealt with in this section of this SSR.

Table 5.11.34
Regulatory Compliance Matrix

Regulation	Regulation/Section	Issue	Section where covered
Regulations on Licensing of Sites for New Nuclear Installations (Department of Energy, 2010)	4 and 5	External events	5.11.6; 5.11.7;5.11.8
RG-0011	11 and Attachment C	Monitoring	5.11.8
RG-0016	6 and 7	Modelling	5.11.7

5.11.11 Conclusions

A comprehensive investigation of the geohydrology of the site has been carried out in order to obtain the required level of understanding of the site characteristics in support of the SSR and the licence application. On the basis of the results and knowledge gained to date, the following key conclusions are drawn:

- There are two aquifers present at the site, the upper intergranular Sandveld Aquifer and the lower fractured rock Malmesbury Aquifer. The former is a major aquifer to the north and east of the site where it is extensively exploited by the CCT as a water resource, e.g. the Witzand and Silwerstroom wellfields, supplying the nearby town of Atlantis.
- Groundwater levels are relatively shallow and flow is generally in a westerly to southwesterly direction towards the Atlantic Ocean.
- Rainfall events influence groundwater levels on site with higher levels during winter rainfall periods and lower levels during dry summer periods. However, water levels in both aquifers only vary by <1 m seasonally in the site boreholes.
- The monitoring period has coincided with both ‘wet’ and ‘dry’ periods, with 2014 being classed as very wet and the period 2015 to 2018 being classed as a drought, with 2016 to 2017 constituting a severe drought according to the SPI method.
- Groundwater quality is moderate with EC in most cases <300 mS/m and the groundwater is slightly alkaline to alkaline and of a mixed NaCl and $Ca(HCO_3)_2$ type.
- Extensive use is made of groundwater in the region, both locally on a small-scale and with the town of Atlantis reliant on the two nearby wellfields described above.

- Test pumping of the Aquarius Wellfield, located on the site, during the severe drought in 2018 gave similar yields to those when it was first established in 1996, i.e. a combined yield of 29.5 ℓ/s. This indicates a buffering effect of the Sandveld Aquifer to climatic extremes, at least in terms of a timespan of a few years, which is attributed to its high porosity and storativity.

- The shallow water table and saturated and unconsolidated sediments of the Sandveld Aquifer will require dewatering prior to excavations for nuclear installation foundations, as per the KNPS.

- Numerical model simulations indicate potential inflows of *c*.20 ℓ/s into proposed foundation excavations, with a cut-off wall and under average recharge conditions. This compares very well with the actual pumping rate required for dewatering of the KNPS foundation excavation, which was 21 ℓ/s. The zone of drawdown should be contained to the site.

- Numerical model simulations for dewatering with a sea level rise of 2.3 m by 2100 and increased recharge translates into a 4 to 5 m rise in groundwater level at the site and shows higher inflows of up to 27 ℓ/s, with a cut-off wall. The zone of drawdown is still contained to the site. However, given the site development timeline, this scenario is unlikely.

- Dewatering of Nuclear-1 foundations will not affect the Aquarius Wellfield and *vice versa,* under all climatic scenarios.

- Contaminant transport scenarios, including a worst-case of a leak over the entire Nuclear-1 footprint with a surrogate 100 per cent concentration source contaminant and with Sr-90 equivalent K_d shows minimal spread after 50 years. Assuming a localised leak for one month nearest the Aquarius Wellfield also shows very limited spread after 2 and 50 years.

- Groundwater level and quality monitoring since mid-2008 has not shown any anomalous or concerning trends that could affect nuclear safety, apart from the need to cater for corrosive conditions in any construction below the water table.

- Given the Langelier saturation indices for the Sandveld Aquifer groundwater and the coastal environment, use of corrosion resistant materials must be considered in the nuclear installation(s) design.

- There are potential long-term issues associated with climate change that could impact site activities, depending on the timing of the latter. Worst-case scenarios were used in the numerical modelling to allow for such events. However, there are limitations on the accuracy of such long-term predictions in terms of both groundwater (e.g. recharge) and numerical models (simplification of the “real world”).

The investigation and monitoring periods have been relatively long at 13 years, and the conceptual and numerical models are considered to be robust and adequate to provide a realistic representation of geohydrological conditions at the site. The KNPS has been operational since 1985, thus providing for a significant period for data gathering and data analysis. The nearby Atlantis Aquifer is also one of the most intensively studied aquifers in the country. However, a key uncertainty is the future impact of climate change on, for example sea level and site groundwater levels. The numerical flow model will need updating as and when new data or insights are obtained and depending on the timing of site activities with respect to climate change and sea level rise for example.

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APPENDICES

The following appendices are provided in electronic format:

Appendix 5.11.A
Historical Borehole Data

Appendix 5.11.B
Hydrocensus Data (2007)

Appendix 5.11.C
Surface Geophysics

Appendix 5.11.D
Exploration Borehole Data & Logs

Appendix 5.11.E
Down-hole EC/pH/Temp and Video Camera Survey, Pump and Packer Test Data

Appendix 5.11.F
Chemical Laboratory Analyses and Monitoring Database

Appendix 5.11.G
Radionuclide Analyses

Appendix 5.11.H
Isotope Analyses

Appendix 5.11.I
Adsorption Testing Report

Appendix 5.11.J
Numerical Model and Validation & Verification Reports

Appendix 5.11.K
Quality Data Pack