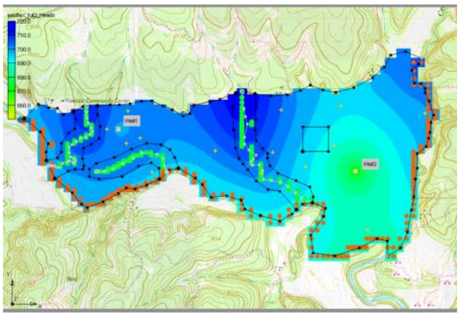
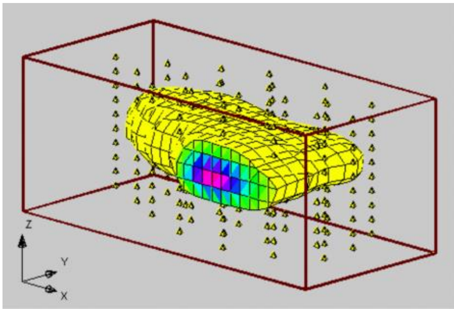
ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') AND ASSOCIATED INFRASTRUCTURE

Geohydrology Environmental Impact Report

September 2015





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September 2015

DECLARATION OF INDEPENDENCE

I, Peter Nigel Rosewarne as duly authorised representative of SRK Consulting, hereby confirm my independence (as well as that of SRK Consulting) as a specialist and declare that neither I nor SRK Consulting have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect of which GIBB was appointed as environmental assessment practitioner in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), other than fair remuneration for worked performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station ('Nuclear-1'). I further declare that I am confident in the results of the studies undertaken and conclusions drawn as a result of it – as is described in my attached report.

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EXECUTIVE SUMMARY

This assessment covers the impacts and mitigation measures associated with the construction and operation of a conventional Nuclear Power Station (NPS) and associated infrastructure at three sites, in the Eastern (1) and Western (2) Cape. The sites were originally identified as a result of site investigations undertaken since the 1980s and from this EIA Scoping Study. This specialist study covers Geohydrology and was carried out by SRK Consulting, with assistance from the Institute for Groundwater Studies at the University of the Free State and North-West University on the numerical modelling.

This impact study comprises the baseline information and an impact assessment for the following sites:

1. Duynefontein;
2. Bantamsklip; and
3. Thyspunt.

The study provides an overall assessment of the impact of a nuclear facility on the aquifer hydrodynamics and vice versa. The Terms of Reference for the specialist Geohydrological Assessment are to investigate:

- The existence and location of regional / local aquifers and other relevant geohydrological units relative to the sites, e.g. aquitards, fractures, boundaries;
- Groundwater observations including information about hydraulic conductivity / transmissivity, groundwater levels and their fluctuations, monitoring of groundwater chemistry and resistance of soil-cement foundations to chemical attack;
- The possibility of groundwater contamination, flooding by groundwater and material degradation due to groundwater attack;
- The effect of withdrawal of groundwater from neighbouring areas on flow of groundwater at the sites;
- A 3D conceptual geohydrological model showing aquifers, groundwater levels, aquifer boundaries, and groundwater flow directions;
- A 3D numerical flow model to simulate regional, local and site specific response of the groundwater system to natural and manmade influences, e.g. seasonality, dewatering during construction, abstraction from wellfields;
- A contaminant transport model to simulate the fate of any contaminants introduced into groundwater systems from operation of the sites; and
- A risk assessment of the impacts of the NPSs on the receiving environment.

Extensive and detailed work has been carried out at all three sites as part of this assessment, including a hydrocensus, surface geophysics, drilling, test pumping, packer tests, chemical analysis, numerical flow and transport modelling and monitoring.

Four potential environmental impacts involving groundwater have been identified, *viz.*:

- Depletion of local aquifers;
- Degradation of wetlands / phreatophytes/ seeps / springs[1];

[1] Please note that although the activities and geohydrological processes leading to impacts on wetlands are discussed this report, the impacts on wetlands are assessed in the Freshwater Ecology

- Contamination of groundwater; and
- Contamination of the shore zone by seawater intrusion.

Two potential impacts of the environment on the NPS have been identified, *viz*:

- Degradation of infrastructure; and
- Flooding by groundwater.

The three sites are all located in coastal environments with so-called EIA Corridors within which the NPS and related infrastructure will be located. There are, therefore, certain key geohydrological characteristics that are likely to govern groundwater occurrence and behaviour at the sites. These are:

- There is unlikely to be any downstream groundwater use;
- Groundwater at the site will be near / at the end of its flow path;
- There will be a component of groundwater flow towards the water table (i.e. upwards);
- Groundwater levels will be near the ground surface;
- The bedrock may comprise a wave-cut platform;
- The receiving environment / downstream receptor of any contamination will be the shore zone / sea;
- There is likely to be a two aquifer system at the site, with an upper intergranular and a lower fractured rock aquifer;
- These two aquifers are likely to be in hydraulic connection but may be separated by a weathered zone in the bedrock possibly constituting an aquitard;
- Local recharge may only affect the upper aquifer. Deeper aquifers may be recharged further inland, possibly many kilometres from each site;
- Groundwater quality may be relatively poor because of a combination of the length of the flow path, time for interaction with aquifer materials and proximity to the sea (sea-water intrusion, wind-blown salts);
- Groundwater flow rates are likely to be relatively slow because of low hydraulic gradients;
- There will be an interface between 'fresh' groundwater from inland and saline groundwater in the shore-zone;
- Groundwater may feed wetlands and coastal springs / seeps which support sensitive ecosystems; and
- Liquid radioactive emissions will not affect existing groundwater users directly. However, any air emissions could be transported inland by prevailing winds and contaminate the groundwater by being incorporated into rainfall recharge.

These characteristics have been taken into account in the approach and execution of this study and played a major role in the impact assessment ratings. At the Bantamsklip site it has been established that no viable aquifers are present, whereas viable aquifers are present at Thyspunt (primary and secondary) and Duynefontein (secondary and primary further inland).

The impact rating of the potential environmental impacts is summarised as follows for the construction and operational phases:

Assessment (a separate but related Appendix to the Environmental Impact Report). The assessment of impacts in the Freshwater Ecology Report is based on the sources of impact discussed in the geo-hydrological assessment.

- Flooding by groundwater: ***Medium*** at all three sites without mitigation and ***Low*** with mitigation;
- Depletion of local aquifers: ***Medium*** at Thyspunt and ***Low-Medium*** at Bantamsklip and Duynefontein without mitigation and ***Low*** at all three sites with mitigation;
- Non-radioactive contamination: ***Medium*** at all three sites without mitigation and ***Low*** with mitigation;
- Degradation of infrastructure: Duynefontein overall index slight to serious corrosion and minor scaling. Bantamsklip overall index slight to serious corrosion and minor scaling. Thyspunt overall index non-corrosive to corrosive and scaling.
- Contamination with radioactive material under normal reactor operation: ***Low-Medium*** at all three sites without mitigation and ***Low*** with mitigation;
- No go option: ***Low*** impact at Bantamsklip and ***High*** at Thyspunt and Duynefontein without mitigation, and ***Low*** at Bantamsklip and ***Medium*** at Thyspunt and Duynefontein with mitigation.

The low ratings are largely a function of the sites being situated in coastal zones with groundwater being at/near the end of its flow path, minimal downstream groundwater receptors and application of tried and tested mitigation measures. Site sensitivity (excluding wetlands, which are dealt with in a separate report) is rated as follows:

- Bantamsklip: Low;
- Duynefontein: Low along the coast increasing in sensitivity inland;
- Thyspunt: Mostly Medium.

Essential mitigation measures include the following:

- Ongoing operation of suitably designed groundwater monitoring networks to cover water levels and quality in all aquifers/wetlands;
- Use of cut-off walls around excavations to a) limit the spread of drawdown during construction and b) maintain stable excavation walls and safe working conditions;
- Use of managed artificial recharge of groundwater pumped from excavations during dewatering to maintain wetlands/springs/seeps and phreatophytes;
- Siting of the NPS excavation on the site within the EIA Corridor such that the impacts identified can be reduced in significance, e.g. avoiding seismically capable faults, fracture zones, wetlands and coastal seeps (assumes groundwater control mitigation measures in place);
- Use of corrosion-resistant foundations, pipes and fittings where infrastructure will be located below the water table;
- The potential for scale formation must be taken into account in the design and maintenance of appropriate structures at the Thyspunt site;
- Development of a remediation/mitigation protocol prior to construction so that measures are documented and in place to deal rapidly with any on-site pollution incidents or signs that predicted drawdown levels have been exceeded during construction.

Based on the geohydrological assessment presented in this specialist report, all three sites are environmentally acceptable, in terms of groundwater, for the development of an NPS.

The confidence level of all information presented in this specialist report is high.

PLEASE NOTE:

This report has been amended as per the recommendations of the Peer Review Report compiled by GCS (Pty) Ltd (Appendix E37 of the Revised Draft EIR Version 2)

ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') AND ASSOCIATED INFRASTRUCTURE
GEOHYDROLOGY

CONTENTS

TABLES

FIGURES

GLOSSARY

Anisotropic: Having some physical property that varies with direction.

Aquifer: A geological formation that has structures or textures that hold water or permit appreciable water movement [from the National Water Act, 1998 (Act No. 36 of 1998)]. Also defined as the saturated zone of a geological formation beneath the water table, capable of supplying economic and usable volumes of groundwater to borehole(s) and / or springs.

Aquifer boundary: A physical barrier to groundwater flow, e.g. geological faults, intrusions (e.g. dykes), lithological changes and topographical flow changes (e.g. quaternary catchment boundaries). Aquifer boundaries induced flow changes and effects integral aquifer test modelling equations.

Aquifer system: A heterogeneous body of interlayered permeable and less permeable material that act as a water-yielding hydraulic unit covering a region.

Aquitard: A geological formation with low permeability that retards and restricts the vertical and / or horizontal movement of groundwater, but does not prevent the movement of groundwater.

Artesian borehole: Groundwater held under pressure in porous rock or soil confined by upper-lying impermeable geologic formations rises to the surface under internal hydrostatic pressure when a borehole is drilled through the impermeable formation. An artesian borehole is free flowing.

Attenuation: The breakdown or dilution of contaminated water as it passes through and aquifer/sand/soil or rock.

Baseflow: The sustained low flow in a river during dry and / or fair weather conditions, but not necessarily all contributed by groundwater; includes contributions from delayed interflow and groundwater discharge.

Blow yield: The volume of water per unit of time blown from a borehole during drilling, to measure the potential yield per water strike and the total potential yield of the borehole (measured in L/s).

Borehole: Includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer [from the National Water Act, 1998 (Act No. 36 of 1998)].

Catchment: The area from which any rainfall will drain into the watercourse, contributing to the runoff at a particular point in a river system, synonymous with the term river basin.

Conceptual model: A simplified, schematic representation of each site, which includes sources, pathways and receptors, as well as the main process characteristics of the geohydrological system. An idealisation of the geohydrological system at the sites on which the numerical model is based. The conceptual model also includes assumptions on the hydrostratigraphy, material properties, dimensionality, and governing processes.

Cone/Zone of depression: A depression in the groundwater table or potentiometric surface that often has the shape of an inverted cone and develops around a borehole from which groundwater is being withdrawn. It may be elliptical in fractured aquifers and is referrred to as a zone in this report.

Confined aquifer: An aquifer in which the groundwater is under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined groundwater occurs.

Contamination: The introduction of any substance into the environment by the action of humans.

Discharge area: An area in which subsurface water, including water in the unsaturated and saturated zones, is discharged at the land surface.

Drawdown: The lowering of the water table in and around a pumping borehole. It is measured as the difference between pumping groundwater level and the original or rest groundwater level.

Durov diagram: A graphical presentation using cation and anion hydrochemical facies, similar to a Piper Diagram, with a projection to a 4^{th} dimension, such as electrical conductivity. The Durov Diagram consists of five fields, two triangular and three rectangular. This diagram provides, on a single illustration, a visual characterisation of the eight major ions and two other properties of groundwater. It is also used to compare groundwater chemistry from different aquifer systems.

Ecosystem: An organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.

Electrical conductivity: A measurement of the ease with which water conducts electricity. Distilled water conducts electricity poorly, while seawater, with its very high salt content, is a very good conductor of electricity.

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

Fault: A zone of displacement in rock formations resulting from tensional forces or compression in the earth's crust.

Formation: A general term used to describe a sequence of rock layers.

Fracture: Cracks, joints or breaks in the rock that can enhance water movement.

Geohydrology: The study of the properties, circulation and distribution of groundwater, in practise used interchangeably with hydrogeology; but in theory hydrogeology is the study of geology from the perspective of its role and influence in hydrology, while geohydrology is the study of hydrology from the perspective of the influence on geology.

Global meteoric water line: Is an equation defined by the geochemist Harmon Craig that states the average relationship between hydrogen and oxygen isotope ratios in natural terrestrial waters, expressed as a worldwide average.

Groundwater flow: The movement of water through openings and pore spaces in rocks below the water table, i.e. in the saturated zone. Groundwater naturally drains from higher-lying areas to low-lying areas such as rivers, lakes and the oceans. The rate of flow depends on the slope of the water table and the transmissivity of the geological formations.

Groundwater resource: All groundwater available for beneficial use, including humans, aquatic ecosystems and the greater environment.

Groundwater: Water found in the subsurface in the saturated zone below the water table or piezometric surface, i.e. the water table marks the upper surface of groundwater systems.

Humic layer: An organic layer of soil, made up mostly of leaf litter and humus (decomposed organic matter).

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

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

Intergranular aquifer: Groundwater contained in intergranular interstices of sedimentary and weathered formations.

Leachate: Any liquid, including any suspended components in the liquid that has percolated through or drained from human-emplaced materials.

Lineaments: A major, linear, topographic feature of regional extent of structural/ volcanic origin, most easily appreciated from remote sensing data, e.g. fault system.

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

Minor aquifer system: Fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability; the aquifer extent may be limited and the groundwater quality variable. Although these aquifers seldom produce large quantities of groundwater, they are important both for local supplies and in supplying base flow for rivers.

Non-aquifer system: Formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities, water quality may also be such that it renders the aquifer as unusable, groundwater flow through such rocks does take place and needs to be considered when assessing the risk associated with persistent contaminants.

Numerical modelling: The analysis of geohydrological processes using computer models.

Perched water table: Localised, unconfined groundwater separated from the underlying main body of groundwater by an unsaturated zone, i.e. the local water table is not in hydraulic continuity with the regional groundwater system.

Phreatophyte: A plant with a deep root system which obtains water from the groundwater table or the capillary zone above the water table.

Piper diagram: The Piper diagram not only shows graphically the nature of a given water sample, but also dictates the relationship to other samples. For example, by classifying samples on the Piper diagram, geologic units can be identified with chemically similar water, and define the evolution in water chemistry along the flow path. Two data points are plotted on the cation and anion triangles and are then combined into a quadrilateral field that shows the overall chemical property of the water sample.

Poor aquifer system: see non-aquifer system.

Potentiometric surface: The potential level (an imaginary surface) to which groundwater will rise above the groundwater level in an aquifer in a borehole that penetrates a confined aquifer; if the potential level is higher than the land surface, the borehole will overflow. See artesian borehole and confined aquifer.

Quaternary catchment: A fourth order catchment in a hierarchal classification system in which a primary catchment is the major unit.

Radioactivity: The spontaneous emission of radiation from the nucleus of an unstable atom, resulting in emission of energy in the form of alpha, beta, or gamma rays. As a consequence of this emission, the radioactive atom is converted, or decays, into an atom of a different element that might or might not be radioactive.

Recharge area: An area over which recharge occurs.

Recent: Time period covering the last 10 000 years of the Earth's geological history

Recharge: The addition of water to the zone of saturation, either by the downward percolation of precipitation or surface water and / or the lateral migration of groundwater from adjacent aquifers.

Runoff: All surface and subsurface flow from a catchment, but in practise refers to the flow in a river, i.e. excludes groundwater not discharged into a river.

Saline intrusion: Replacement of freshwater by saline water in an aquifer, usually as a result of groundwater abstraction.

Saline water: Water that is generally considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids.

Saturated zone: The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.

Seep: A diffuse wetland area where interflow and groundwater emerges, usually at a slow rate or volume, and thus has a perpetually saturated soil but may have little or no standing water.

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

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

Spring: A point where groundwater emerges, usually as a result of topographical, lithological and / or structural control.

Storativity: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is a volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. This is a measure of the water stored and released in an aquifer and is used to quantify the safe yield of an aquifer system.

Transmissivity: Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer. Transmissivity is used to calculate the yield of a borehole, determine the safe yield of an aquifer system and predict groundwater movement.

Unconfined aquifer: An aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.

Unsaturated zone: That part of the geological stratum above the water table where interstices and voids contain a combination of air and water; synonymous with the zone of aeration and vadose zone.

Vadose zone: The unsaturated zone above the water table where interstices contain a combination of air and water.

Vulnerable aquifer: May be contaminated or is easily susceptible to contamination from human and / or natural sources. A vulnerable aquifer is often not protected by overlying layers of soil serving to slow the rate of water movement from the ground surface. Improperly constructed or maintained boreholes can also increase the vulnerability of an aquifer by providing a direct route for contaminants to enter the aquifer.

Water Management Area: An area that is established as a management unit in the national water resource strategy within which a catchment management agency will conduct the protection, use, development, conservation, management and control of water resources [from the National Water Act, 1998 (Act No. 36 of 1998)].

Water table: The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.

Wellfield: An area containing more than one pumping borehole that provides water to a public water supply system or single owner (i.e. Municipality).

Wellpoint: A shallow, small diameter hole used to abstract groundwater from a primary aquifer.

Wetland: Land that is transitionary between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil [from the National Water Act, 1998 (Act No. 36 of 1998)].

ABBREVIATIONS

3D:	Three dimensional
AEC:	Atomic Energy Corporation of South Africa Ltd
AWRMS:	Atlantis Water Resource Management Scheme
c.:	approximately
CMB:	Chloride Mass Balance, recharge estimation method
CoCT:	City of Cape Town
CV:	Coefficient of Variation
DEA&DP:	Department of Environmental Affairs and Development Planning
***DEAT*:**	Department of Environmental Affairs and Tourism (now Department of Environmental Affairs)
DOH:	Department of Health
DTM:	Digital Terrain Model
***DWAF*:**	Department of Water Affairs and Forestry (became Department of Water Affairs, now Department of Water and Sanitation)
DWA:	Department of Water Affairs
EC:	Electrical conductivity, measured as milli-Siemens per metre (mS/m)
EIA:	Environmental Impact Assessment
EIR:	Environmental Impact Report
EMP:	Environmental Management Plan
GA:	General Authorisation
GEP:	Groundwater Exploitation Potential
GMWL:	Global Meteoric Water Line
GPS:	Global Positioning System
GRA-II:	Groundwater Resource Assessment Phase 2 Project
GRP:	Groundwater Resource Potential
GRU:	Groundwater Resource Unit
ha:	hectares
hr:	hours
IAEA:	International Atomic Energy Agency
ISSR:	Intermediate Site Safety Report
IWRM:	Integrated Water Resources Management
IWWMP:	Integrated Waste and Water Management Plan
K:	Hydraulic conductivity, measured as m/d
KNPS:	Koeberg Nuclear Power Station
L/s:	litres per second

m/d:	metres per day
m^3/a:	cubic metres per annum
m^3/d:	cubic metres per day
Ma:	Million years ago
MAE:	Mean annual evaporation
mamsl:	metres above mean sea level
MAP:	Mean annual precipitation
MAR:	Mean annual runoff
mbc:	metres below collar
mbgl:	metres below ground level
mg/L:	milligrams per litre
Mm^3/a:	million cubic metres per annum
mS/m:	milli-Siemens per metre
NECSA:	Nuclear Energy Corporation of South Africa
NEMA:	National Environment Management Act, 1998 (Act No. 107 and 1998)
NGDB:	National Groundwater Database
NNR:	National Nuclear Regulator
NSIP:	Nuclear Siting Investigation Programme
NWA:	National Water Act, 1998 (Act No. 36 of 1998)
PBMR DPP:	Pebble Bed Modular Reactor Demonstration Power Plant
SSR:	Site Safety Report
S_y:	Specific yield
SABS:	South African Bureau of Standards
SANS:	South African National Standard
SRK:	SRK Engineers and Scientists (South Africa) (Pty) Ltd
SSR:	Site Safety Report
T:	Transmissivity, commonly reported in units of m^2/d
TMG:	Table Mountain Group
ToR:	Terms of Reference
WHO:	World Health Organisation
WMA:	Water Management Area
WRC:	Water Research Commission
WSA:	Water Services Act (Act No. 108 of 1997)
WWTW:	Wastewater treatment works

1 INTRODUCTION

1.1 Background

This specialist study covers Geohydrology and has been undertaken by SRK Consulting (SRK) to inform the Environmental Impact Assessment (EIA) conducted by Gibb in support of Eskom's Nuclear-1 project.

This report investigates the existing groundwater conditions as well as the impacts and mitigation measures associated with geohydrology for the construction and operation of a conventional nuclear power station (NPS) and associated infrastructure at three sites, one in the Eastern and two in the Western Cape (see **Figure 1.1**). The sites have been identified based on site investigations undertaken since the 1980s (Eskom 1994 a, b, c), as well as the scoping phase of this EIA.

This assessment comprises the baseline information and an impact assessment for the following sites (**Figure 1.1**):

1. Duynefontein;
2. Bantamsklip; and
3. Thyspunt.

Eskom proposes to construct a NPS of the Pressurised Water Reactor type technology, with a capacity not exceeding 4 000 MWe. The proposed NPS will include nuclear reactor(s), turbine complex, spent fuel and nuclear fuel storage facilities, waste handling facilities, intake and outfall structures and various auxiliary services infrastructure. The main infrastructure buildings as listed above will be situated in a so-called EIA Corridor Area (defined in the main EIA report), which is shown schematically on the various site plans in **Section 2**. Other associated buildings such as security, reservoirs, bulk stores, weather station and nature conservation area may be located elsewhere within the property boundaries.

1.2 Terms of Reference

The assessment of impacts is broadly undertaken in accordance with the guidelines provided in the Guideline Document: EIA Regulations (DEAT, 1998), the NEMA principles and Section 24(4) of NEMA (as amended), as appropriate to this geohydrological study. In addition, the following General Terms of Reference (ToR) applies to each of the specialist studies:

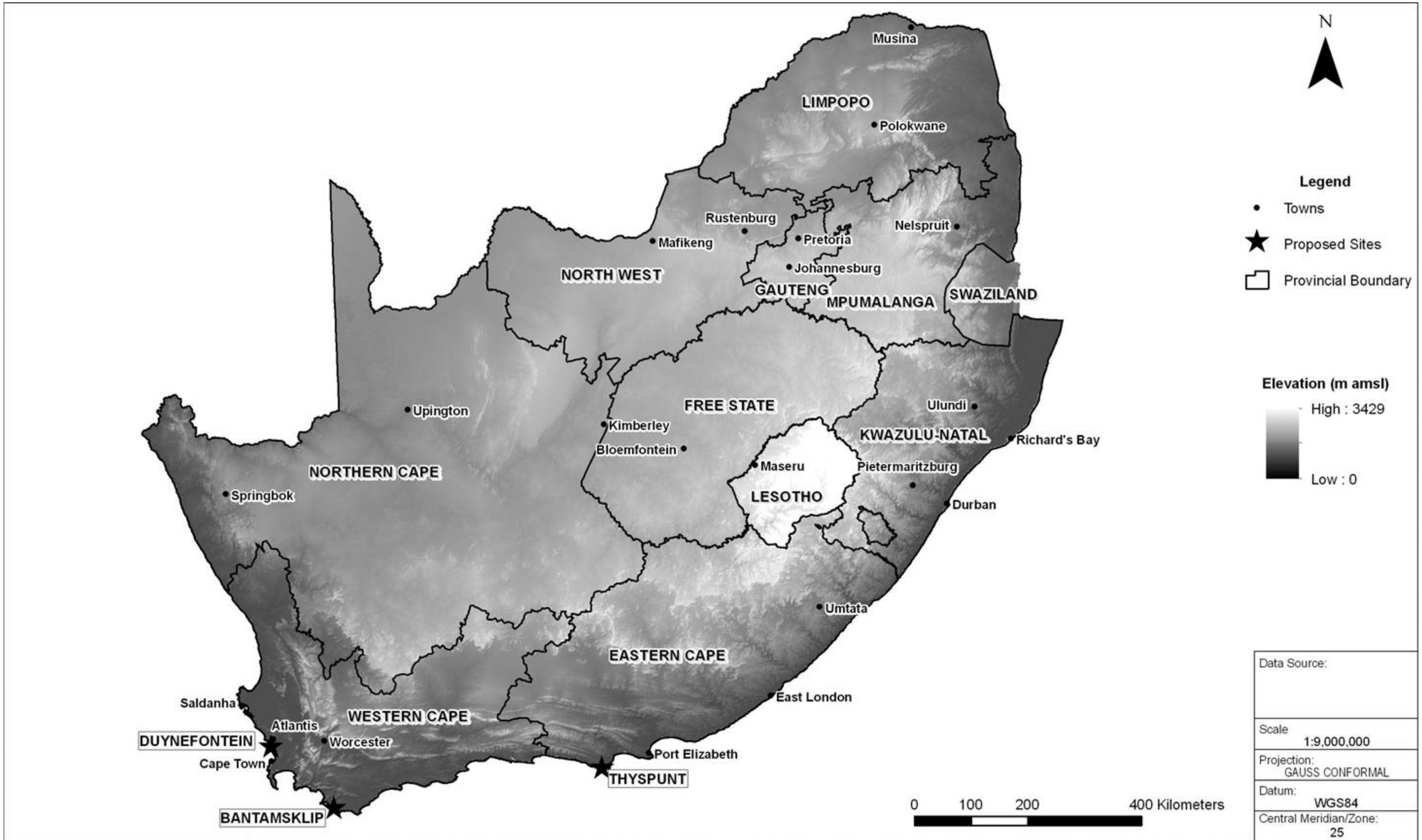
- Discussion of relevant policies and frameworks, where applicable;
- The affected environments (baseline information) as well as inferred changes to the baseline environment considering the effects of climate change;
- Identification of information gaps, limitations and additional information required;
- Description of the anticipated impacts using the impact assessment criteria as defined in **Subsection 1.2.4** for the various phases of the project, i.e. design, construction and operation;
- Development of relevant mitigation measures;
- Specialists must determine the effects of climate change on the proposed development and *vice versa* in terms of their fields of expertise;

- Utilisation of information from the existing Koeberg NPS (KNPS) in order to determine the cumulative impacts at the Duynefontein site;
- Assessment of the impacts associated with the desalination plant, i.e. brine discharge to the ocean;
- Derivation of monitoring and auditing programmes, where necessary.

The study provides an overall assessment of the impact of a nuclear facility on the aquifer hydrodynamics and *vice versa*. The ToR for the specialist Geohydrological assessment is to investigate:

- The existence and location of regional / local aquifers and other relevant geohydrological units relative to the sites, e.g. aquitards, fractures, boundaries;
- Groundwater observations including information about hydraulic conductivity (K) / transmissivity (T), groundwater levels and their fluctuations, monitoring of groundwater chemistry and resistance of soil-cement foundations to chemical attack;
- The possibility of groundwater contamination, flooding by groundwater and material degradation due to groundwater attack;
- The effect of withdrawal of groundwater from neighbouring areas on flow of groundwater at the sites;
- A 3D conceptual geohydrological model showing aquifers, groundwater levels, aquifer boundaries, and groundwater flow directions;
- A 3D numerical flow model to simulate regional, local and site-specific response of the groundwater system to natural and manmade influences, e.g. seasonality, dewatering during construction, abstraction from wellfields;
- A contaminant transport model to simulate the fate of any contaminants introduced into groundwater systems from operation of the sites; and
- A risk assessment of the impacts of the sites on the receiving environment.

A previous version of this assessment was produced in March 2011. However, due to the large number of comments received from I&APs and additional work carried out on monitoring of wetlands-groundwater interaction at all three sites, an updated version of the assessment (this report) has now been produced.



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srk consulting

NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSD POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY

LOCATION OF THE PROPOSED NUCLEAR POWER STATION SITES

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Revision: B Date: 31 10 2012

1.3 Legislative Framework

The main legislation and applicable guidelines / quality standards covering geohydrological issues applicable to a NPS and site investigation thereof are:

- National Water Resource Strategy (NWRS, 1st Ed., September 2004);
- National Water Act, 1998 (Act No. 36 of 1998) [NWA]: Issues include groundwater abstraction / discharge (e.g. from excavation dewatering rather than supply boreholes) and groundwater quality, water use Licence Applications, General Authorisations and General Standards for effluent discharge;
- Water Services Act , 1997 (Act No. 108 of 1997) [WSA];
- National Water Policy White Paper, April 1997;
- National Environment Management Act, 1998 (Act No. 107 and 1998) [NEMA]: Issues include an Environmental Management Plan (EMP) for site work such as drilling;
- Department of Environmental Affairs and Development Planning's (DEA&DP) Guideline for Involving Hydrogeologists in EIA Processes (June 2005) (Saayman, 2005);
- Department of Water Affairs and Forestry's (DWAF) Integrated Water Resource Management: Guidelines for Groundwater Management in Water Management Areas in South Africa (DWAF, 2004): Issues include groundwater resource assessment, allocation and monitoring;
- Eskom Technical Specification for Site Safety Reports.
- South African Bureau of Standards (SABS) – South African National Standard for Drinking Water (SANS 241 : 2006; Ed. 6.1; December 2006): Specifies the quality of acceptable drinking water, defined in terms of microbiological, physical, organoleptic and chemical determinands, at the point of delivery (e.g. boreholes and wellpoints). It describes two classes of drinking water: Class I, which is considered to be acceptable for lifetime consumption, and is the recommended compliance limit; Class II, which is considered to represent drinking water for consumption for a limited period (SANS, 2006).
- DWAF, the Department of Health and the Water Research Commission's (WRC) Quality of Domestic Water Supplies, Volume 1: Assessment Guide, 2nd Ed. 1998 (WRC No.: TT 101/98) (DWAF, 1998).
- World Health Organisation's (WHO) Drinking Water Quality Series: Provides a structured approach to analysing hazards to groundwater quality, assessing the risk they may cause for a specific supply, setting priorities in addressing these, and developing management strategies for their control (WHO, 2006).
- International Atomic Energy Agency (IAEA) Safety Requirements No. NS-R-3, Site Evaluation for Nuclear Installations.
- IAEA Safety Guide No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants.
- 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.
- World Meteorological Organization WMO-No 168 (1994) Guide to Hydrological Practices.

The NWA is the principal legal instrument relating to water resource management in South Africa and contains comprehensive provisions for the protection, use, development, conservation, management and control of the country's water resources. In addition, the management of water as a renewable resource must be carried out within the framework of environmental legislation, i.e. NEMA.

A key aspect of the National Water Policy is Integrated Water Resources Management (IWRM). This recognises that water resources can only be successfully managed if the natural, social, economic and political environments in which water occurs and is used are taken into consideration. IWRM aims to strike a balance between the use of water resources for livelihoods and conservation of the resource whilst promoting social equity, environmental sustainability and economic growth and efficiency.

1.4 Impact Assessment Methodology

The impact assessment has been carried out using the guidelines listed in **Table 1.1**, as supplied by Gibb.

Table 1.1: Impact Assessment Criteria and Rating Scales

Criteria	***Rating Scales***	***Notes***
Nature	Positive	This is an evaluation of the type of effect the construction, operation and management of the proposed NPS development would have on the affected environment.
	Negative	
	Neutral	
Extent	Low	Site-specific, affects only the development footprint
	Medium	Local (limited to the site and its immediate surroundings, including the surrounding towns and settlements within a 10 km radius);
	High	Regional (beyond a 10 km radius) to national
Duration	Low	0-5 years (i.e. duration of construction phase)
	Medium	6-10 years
	High	More than 10 years to permanent
Intensity	Low	Where the impact affects the environment in such a way that natural, cultural and social functions and processes are minimally affected
	Medium	Where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way; and valued, important, sensitive or vulnerable systems or communities are negatively affected
	High	Where natural, cultural or social functions and processes are altered to the extent that the impact will temporarily or permanently cease; and valued, important, sensitive or vulnerable systems or communities are substantially affected.
Potential for Impact on Irreplaceable Resources	Low	No irreplaceable resources will be impacted.
	Medium	Resources that will be impacted can be replaced, with effort.

Criteria	*Rating Scales*	*Notes*
	High	There is no potential for replacing a particular vulnerable resource that will be impacted.
Consequence (a combination of extent, duration, intensity and the potential for impact on irreplaceable resources).	Low	A combination of any of the following • Intensity, duration, extent and impact on irreplaceable resources are all rated low • Intensity is low and up to two of the other criteria are rated medium • Intensity is medium and all three other criteria are rated low
	Medium	• Intensity is medium and at least two of the other criteria are rated medium
	High	• Intensity and impact on irreplaceable resources are rated high, with any combination of extent and duration • Intensity is rated high, with all of the other criteria being rated medium or higher.
Probability (the likelihood of the impact occurring)	Low	It is highly unlikely or less than 50% likely that an impact will occur.
	Medium	It is between 50 and 70% certain that the impact will occur.
	High	It is more than 75% certain that the impact will occur or it is definite that the impact will occur.
Significance (all impacts including potential cumulative impacts)	Low	• Low consequence and low probability • Low consequence and medium probability • Low consequence and high probability
	Low to Medium	• Low consequence and high probability • Medium consequence and low probability
	Medium	• Medium consequence and low probability • Medium consequence and medium probability • Medium consequence and high probability • High consequence and low probability
	Medium to High	• High consequence and medium probability
	High	• High consequence and high probability

1.5 Study Areas

For the purpose of this study, a study area covering all relevant quaternary catchment(s) and related Groundwater Resource Units (GRUs) around the sites has been defined to adequately cover local and regional aquifers and other geohydrological features.

1.6 Study Approach

An Inception Report that only provided summary level information as part of the EIA was submitted by SRK during September 2007 (Rosewarne *et al*., 2007). The Inception Report outlined the extent and physiographic setting, geology, groundwater occurrence, groundwater quality and groundwater potential at each of the sites. Further interim and draft reports were compiled in 2008. Since then, additional detailed information has been obtained from various consultancy reports and site work including hydrocensus, surface geophysics, drilling, pumping and packer tests, monitoring and chemical analysis of water samples. These data were then collated and input into a conceptual hydrogeological model for each site and then numerical flow and transport models. Activities carried out in the production of this assessment for each site were therefore:

1. Hydrocensus:
    - Survey of all boreholes/wells/springs within a *c*.5 km radius of each site, noting *inter alia* GPS position, water level, yield, use and field EC and pH, where access and owner information allowed. Water samples were taken for chemical, radionuclide and isotope analyses;
2. Borehole siting
    - Data review and surface geophysics. Liaison with the Council for Geoscience, Wetlands and Geotechnical specialists
3. Drilling Programme:
    - Supervised drilling of exploration / test/monitoring boreholes
    - Surveyed coordinates and surface elevations of the boreholes;
    - Prepare detailed borehole logs for each borehole;
4. Pumping Test Programme:
    - Step drawdown, constant discharge and recovery tests;
    - Determine T and S parameters;
    - Determine K ;
    - Determine sustainable borehole yields;
    - Collect groundwater samples for detailed chemical and isotope analysis;
    - Calculate the areal extent of drawdown due to pumping.
5. Down-Hole Video Camera Inspection:
    - The down-hole video camera inspection was carried out to provide detailed information in regard to borehole casing depths, accurate depths of fractures and other geological structures, as well as possibly delineate lithological contacts and therefore improve the accuracy of borehole logs;
    - All inspections were recorded directly onto DVD.
6. Packer Test Programme:
    - Packer tests were carried out to determine K in the upper 20 m of the secondary aquifers, the main zone that might impact on the nuclear foundations and *vice versa*;
    - Packer tests consist of isolating specific sections of a borehole with inflatable packers (bladders) so that formation K tests can be conducted;
    - Such tests allows definition of the vertical distribution of K (pathways for water and contaminant movement) in an aquifer;
    - Packer testing is the standard method of obtaining such detailed information;
7. Monitoring Programme:
    - Building up a database of groundwater levels and quality so that temporal and seasonal fluctuations can be determined;
    - Installation and monitoring of additional boreholes and piezometers in and adjacent to wetlands;
    - Collecting groundwater samples for chemical, radionulcide and isotope analysis.

8. Modelling:
   - A 3D conceptual geohydrological model showing aquifers, groundwater levels, aquifer boundaries, and groundwater flow directions;
   - A 3D numerical flow model to simulate regional, local and site specific response of the groundwater system to natural and manmade influences, e.g. groundwater control during construction, abstraction from wellfields;
   - Additional 3D modelling of wetlands-groundwater interactions;
   - A contaminant transport model to simulate the fate of contaminants introduced into groundwater systems from operation of the sites.

The following basic steps were employed in the modelling process:

- **Collecting and interpreting field data:** An adequate set of field data are essential to understand the natural system and to specify the investigated groundwater problem. The data collection focussed on those aspects that will have the greatest influence on the value of the numerical model to the project deliverables. The quality of the simulations depends largely on the quality of the input data. For the purpose of this assessment, the amount and quality of the data collected is sufficient to carry out the required simulations. However, collection of additional time series monitoring data, e.g. groundwater levels, will enhance the existing data base and allow for updating and refining of the numerical simulations and is being continued at all three sites (approximate six years duration to date).

- Transmissivity in fractured rock aquifers such as the Malmesbury Group and Table Mountain Group aquifers varies naturally across sites and from site to site and apparently inconsistent results are normal. Having T values varying between, e.g. 5 and 180 m^2/day, is not a sign of poor or inadequate data gathering; it is a function of aquifer anisotropy and heterogeneity. For example, it is stated herein that certain low T values are related to the matrix whereas the higher values relate to fractures. Transmissivity cannot be ‘accurately’ determined.

- **Conceptual model:** The natural system is represented by a conceptual model, which includes designing and constructing equivalent but simplified conditions for the real world problem. This approach is followed internationally and is a crucial first step in groundwater modelling. The following data were included in the conceptual model:

  - The known and inferred geological and geohydrological features and characteristics of the area.
  - The rest water levels/piezometric heads of the study area.
  - The interaction of the geology and geohydrology on the boundaries of the study area.
  - A description of the existing and proposed processes and interactions taking place within the study area that will influence the movement of groundwater;
  - Any simplifying assumptions necessary for the development of a numerical model and the selection of a suitable numerical code.

- **Calibration & validation:** Model calibration and validation are required to translate the usually relatively limited and point source data to a regional scale, and in order that the model can be reliably used to make predictions. They also accommodate the simplification of the natural system in the model.

  The area to be modelled is divided into a grid of cells and layers. The dimensions of the former are chosen based on the area to be modelled, density of data points and complexity of the aspect to be simulated. A grid of 50 m x 50 m was selected as being suitable for the Nuclear-1 sites. The number of layers chosen reflects the number of layers actually present at each site; increasing the number of layers does not necessarily improve the accuracy of a model and may in fact lead to a model that is more detailed/ complex than the input data warrant.

  In model calibration, simulated values like potentiometric surface or contaminant concentrations are compared with field measurements. The model input data are then altered within reasonable ranges until the simulated and observed values fit within a chosen tolerance. This enables refinement of point source estimations of e.g. T from test pumping analysis, to more accurately reflect site/ regional values.

  In all numerical model simulations of this nature, the internationally accepted protocol is to first construct a steady state model. This is essential and unavoidable in order to first calibrate the model. Models are simplifications of the real world situation and certain assumptions have to be made in order for them to run properly. This is the standard international procedure for constructing and running numerical flow models.

- **Modelling scenarios:** Alternative scenarios for a given area are then assessed. In order to develop a model of an aquifer system, certain assumptions have to be made, including the following:

  - The system is initially in equilibrium and therefore in steady state.
  - The available information on the geology and field tests is considered as acceptable and representative.

Some general comments that apply to the approach to all three sites related to modelling and related issues are discussed here.

MODFLOW (Harbaugh and McDonald, 1996), a modular three-dimensional finite difference groundwater flow model developed by the U.S. Geological Survey, was the software used during this investigation. It is an internationally accepted and benchmarked modelling package, which calculates the solution of the groundwater flow equation using the finite difference approach. A professional graphical interface, *PMWIN*, developed by Chiang and Kinzelbach (1999), was used to create the model and to analyse and display the modelling results.

Listed below are a few reasons why *MODFLOW* has been selected as the modelling package and more specifically *PMWIN* as the graphical interface:

- *MODFLOW* simulates steady and non-steady state flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination thereof;

- Flow from external stresses such as flow to boreholes, aerial recharge, evapo-transpiration, 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 may be heterogeneous;
- *MODFLOW* is currently internationally the most used numerical model for flow problems;
- *MODFLOW* was used in the numerical flow modelling carried out for the site investigations for the licensing of the KNPS and preliminary work on the Pebble Bed Modular Reactor Demonstration Power Plant site (PBMR DPP);
- *MT3D* mass transport package runs together with *MODFLOW*. Simulation of the transport of solutes can therefore be accomplished.

A limitation of *MODFLOW* is simulation of flow in specific fracture zones. Such zones exist within the study areas but on the scale of the regional and scenario modelling it is considered that *MODFLOW* will provide adequate representation of the system response. This is because the bedrock aquifers at all three sites have a generally fractured (to varying degrees) character rather than consisting of one or more discrete fractures. A further factor supporting the use of *MODFLOW* is that the most important aquifer at each site and the one most likely to be impacted by an NPS is the upper, unconfined and intergranular aquifer, where the assumptions underpinning this computer code are fully met.

A further assumption made is that control of groundwater during excavation of foundations for the NPS will be by means of dewatering and impermeable cut-off walls. There are alternatives such as ground freezing. Ground freezing is a technique that is normally applied to construction features such as shafts and tunnels rather than mass freezing that would be required for a Nuclear-1 type excavation. It should be noted that the dewatering/groundwater control methods mentioned in this assessment are only illustrative and not for design specifications. There will be further more detailed work carried out on these aspects and ground freezing could be considered at this stage and once more detailed site information is gathered. Some reasons why ground freezing has not been considered further in this assessment are:

- It requires a 100 per cent cut-off of groundwater to be effective; any seepage or leakage through the freeze could be catastrophic;
- The size and type of the excavation is not suitable for ground freezing;
- Excavation of frozen soil is more expensive than that of loose, drained soil.

Concerns about flooding of an excavation from a cloudburst or continuous heavy rain are largely unfounded as:

- The dewatering/groundwater control system will be designed to have surplus capacity to deal with such events;
- Extreme rainfall events, e.g. August 2008, monitored at the sites to date, have shown that groundwater level response to such events in the upper primary aquifers is relatively small. This is attributed to the high porosity of the dune sands, overflow of water into wetlands and rapid drainage from the system *via* an underlying cobble layer, where present.

The contaminant transport scenarios modelled are gaseous emissions of tritium under normal reactor operations and liquid emissions of an unspecified but non-radioactive contaminant. The results of the latter are conservative and with the reactors likely to be located close to the coast, potential impacts on aquifers/groundwater are adequately represented.

The numerical modelling work was carried out by Dr. Ingrid Dennis, formerly of the Institute for Groundwater Studies, University of the Free State (UFS), now head of department at North-West University, Potchefstroom. She has a BSc in mathematics and applied mathematics and Honours, MSc and PhD in geohydrology and 19 years of experience. She is widely regarded in the geohydrological community in South Africa as one of the country's leading modellers. Her work was reviewed by the late Professor Gerrit van Tonder of the UFS who had a BSc Hons in geohydrology and MSc and PhD in geohydrological statistics and data analysis. The modelling was also reviewed by Peter Rosewarne (Principal Geohydrologist with 39 years of experience) and Richard Connelly (Principal Geohydrologist with SRK UK with >40 years experience). CVs have been provided.

1.7 Information Sources

Limited site work in the form of drilling and yield testing was carried out by the Atomic Energy Corporation of South Africa Ltd (AEC) at the Bantamsklip and Thyspunt sites in the 1980s. Extensive, detailed work was carried out at the Duynefontein site for the KNPS commissioning and the PBMR DPP project. The Atlantis Aquifer occurring at and around this site is one of the most studied aquifers in South Africa. The author of this report was involved in the development of the boreholes/wellfields supplying St. Francis Bay in 1989 to 1992 and so has extensive knowledge of the local geohydrology around the Thyspunt site. Further very detailed geohydrological work has been carried out for this assessment. A list of references sourced for this study is given in **Section 7**.

1.8 Integration with Other Studies

Several parallel studies have been undertaken for the EIA that are relevant to Geohydrology. These include Geotechnics, Geology, Hydrology, Freshwater Ecology (wetlands), Human Health Risk Assessment and Freshwater Supply. Close liaison with these specialists has been maintained by the Geohydrology team to ensure commonality of purpose and data, sharing of results and best use of available data.

1.9 Assumptions and Limitations

This specialist report has been based on a desk study and detailed site investigations, as listed in **Subsection 1.5**. This impact assessment is therefore not considered to be constrained in any way by availability of data, beyond natural constraints in defining and quantifying geohydrological issues/parameters.

In geohydrology there are only three parameters that can be physically measured – borehole yields, groundwater electrical conductivity (and chemical content) and water levels. All other key parameters, such as transmissivity, storage and recharge, have to be estimated from some form of analytical/numerical process. Geohydrology is therefore an inexact science in which the experience and expertise of the geohydrologist plays a large part (Peter Rosewarne has 39 years of experience). The only 'knowns' for input parameters in any groundwater model carried out anywhere in the world can only be the above three parameters – everything else is by definition an unknown whose values are derived by laboratory analyses, field tests, data analysis and use of text book examples or previous work and application of experience.

Geophysical surveys were carried out across all three sites and assisted with, *inter alia*, borehole siting. Based on the level of information available for each site it is considered to be highly unlikely that there are unknown faults/fractures present that could materially affect groundwater movement.

The best way to improve the confidence in a groundwater model is to collect time series data. An extended groundwater/wetlands monitoring programme was thus initiated by Eskom at the site in February 2010. This programme ran continuously until September 2013 and data loggers are still operational and storing data. Additional boreholes/piezometers have been established and continuous data loggers installed. The monitoring database is being updated on a monthly basis and further flow modelling has been done to input the new data and assess any changes to predicted impacts. This work is being carried out jointly with the wetlands specialist. Monitoring is of the utmost importance to ensure that confidence in the results obtained from numerical modelling can be improved. More than two years' worth of data obtained since the previous version of this report have corroborated the previous findings.

2 DESCRIPTION OF THE AFFECTED ENVIRONMENT

At coastal nuclear sites such as Duynefontein, Bantamsklip and Thyspunt, the nuclear footprint is likely to be located very close to the coastline. In terms of the groundwater cycle, this means that it is located in a groundwater discharge zone. There are, therefore, certain general geohydrological characteristics that are likely to be common to such sites and that must be taken into consideration. These are:

- There is unlikely to be any downstream groundwater use;
- Groundwater at the sites will be near / at the end of its flow path;
- There will be a component of groundwater flow towards the water table (i.e. upwards);
- Groundwater levels will be near the ground surface;
- The bedrock may comprise a wave-cut platform;
- The receiving environment / downstream receptor of any contamination will be the shore zone / sea;
- There is likely to be a two aquifer system at the sites, with an upper intergranular and a lower fractured rock aquifer;
- These two aquifers are likely to be in hydraulic connection but may be separated by a weathered zone in the bedrock possibly constituting an aquitard;
- Local recharge may only affect the upper aquifer. Deeper aquifers may be recharged further inland, possibly many kilometres from the sites;
- Groundwater quality may be relatively poor because of a combination of the length of the flow path, time for interaction with aquifer materials and proximity to the sea (seawater intrusion, wind-blown salts);
- Groundwater flow rates are likely to be relatively slow because of low hydraulic gradients;
- There will be an interface between ‘fresh’ groundwater from inland and saline groundwater in the shore-zone;
- Groundwater may feed coastal springs / seeps which may support sensitive ecosystems;
- On-site leaks of radioactivity will not affect existing groundwater users directly. However, air emissions could be transported inland by prevailing winds and contaminate the groundwater by being incorporated into rainfall recharge.

  These characteristics have been taken into account in the approach and execution of this study and play a major role in the impact assessment ratings.

2.1 Duynefontein

The Duynefontein site has the most information available as detailed studies have been carried out with respect to the siting, construction and operation of the KNPS and planned (cancelled in 2010) PBMR DPP site. This has included extensive drilling, testing, monitoring and numerical flow modelling. The local primary aquifer is also one of the most highly studied in South Africa.

2.1.1 Extent and Physiographic Setting

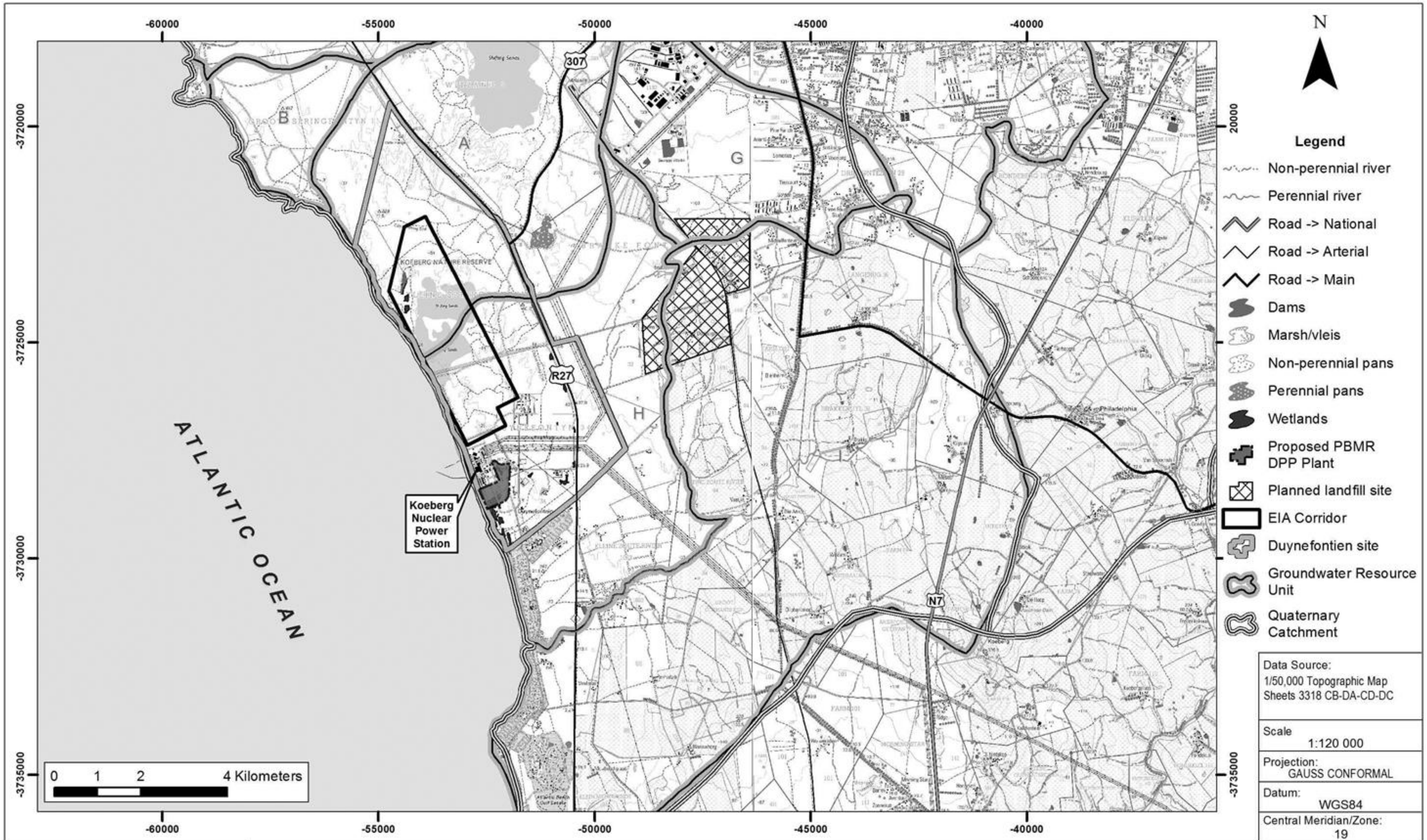
The Duynefontein site is situated along the West Coast, approximately 30 km north of Cape Town CBD (**Figure 2.1**). It is located within the municipal boundaries of the City of Cape Town (CoCT), and is situated on Cape Farm No. 34 Duynefontein (1 257.39 ha in extent), and Coastal Strip Farm 1 375 (area of 37.06 ha). Access to the site is via the R27. A regional landfill site (Hazard rating H:h) and associated infrastructure, to service the CoCT, may be established *c*.4 km north-east of the Duynefontein site, pending the outcome of litigation regarding an alternative site south of Malmesbury. The suburbs of Duynefontein and Melkbosstrand are located *c.*1 km and *c*.2.5 km south, of the Duynefontein site, respectively, while the industrial and residential town of Atlantis is located *c*.10.5 km north-east of the site.

The site falls within quaternary catchment G21B and in the Berg Water Management Area (WMA). The area has been subdivided into eight GRUs based mainly on geology and surface drainage features, as well as the bedrock topography and groundwater flow regime in the unconsolidated Cenozoic-age deposits (Woodford 2007). Based on this work, the site falls within the Duynefontein GRU (Unit H).

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

The Koeberg Nature Reserve, which was proclaimed as a nature reserve in 1991, is found immediately north of the site. The reserve consists predominantly of Strandveld and Acid Sand Plain Fynbos.

The topography is relatively flat with a gentle slope towards the coast. However, both ancient dunes stabilised by vegetation and Recent-age unconsolidated dunes with heights of <10 m are found 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. These rivers all flow in a south-westerly direction towards the coast. These tributaries are generally ephemeral in nature and only flow for short periods after significant rainfall events. Based on the nature of these rivers, Parsons and Flanagan (2006) suggested that groundwater does not discharge into the rivers. 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.



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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
LOCATION OF THE DUYNEFONTEIN SITE

Date:	Compiled by:
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The site has a Mediterranean climate characterised by dry summers and wet winters. The average annual rainfall measured at the KNPS from 1980 to 2004 is 375 mm/a. Maximum rainfall occurs during June (*c*.65 mm), July (*c*.68 mm) and August (*c*.53 mm), while the lowest rainfall occurs during January (*c*.10 mm) and February (*c*.8 mm).

2.1.2 Regional Groundwater Occurrence

The site overlies two aquifer systems; the southern extent of the local, upper intergranular Atlantis Primary Aquifer (Atlantis Aquifer), which forms part of the more regional Sandveld Aquifer, and the deeper weathered, fractured-rock (secondary) aquifer system of the Malmesbury Group.

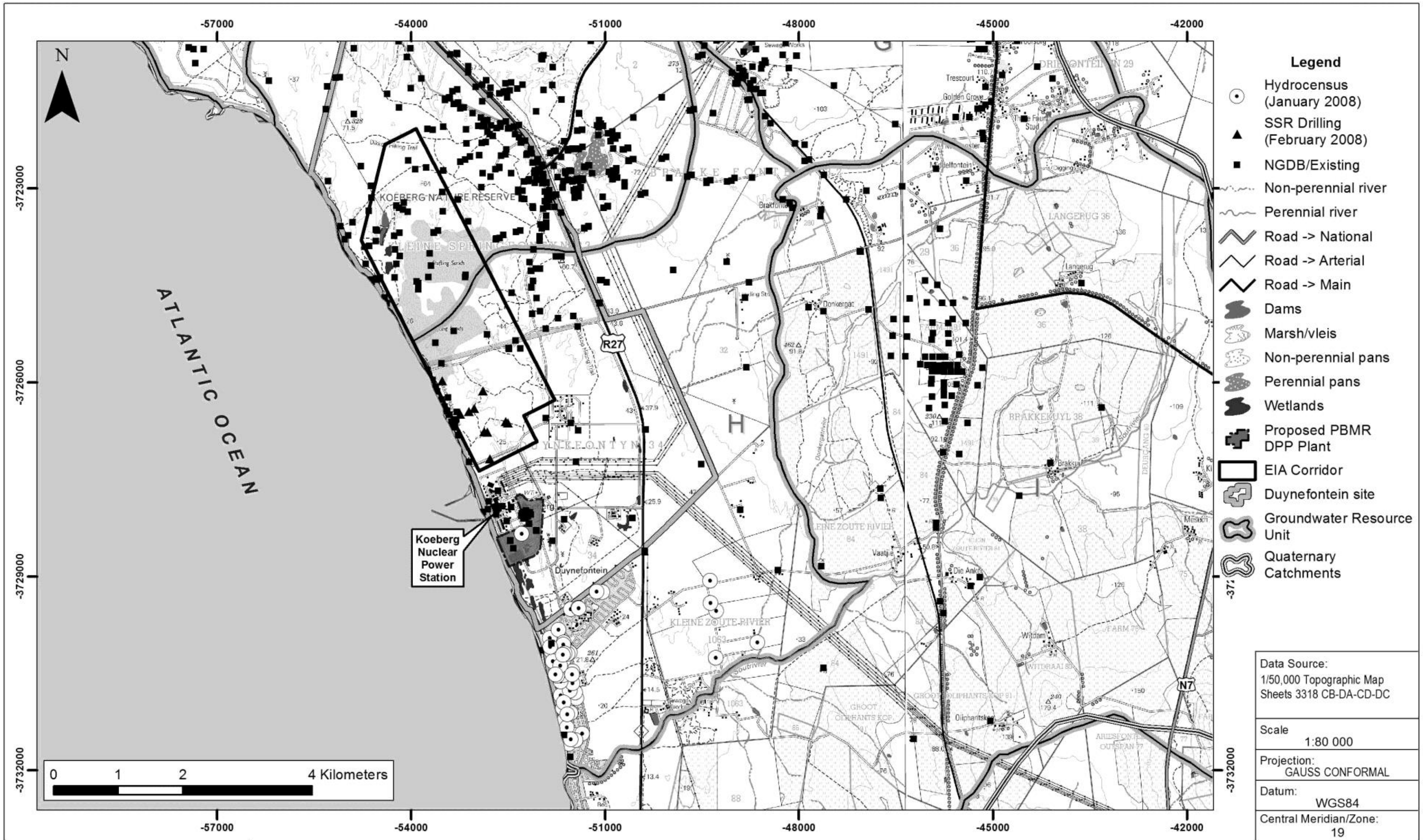
The thickness of the primary aquifer at the site varies between 17 and 25 m, as the rest groundwater level is some 2 to 5 m below ground level (mbgl) and the overall thickness of the sediments is between 14 and 27 m. The results of the various drilling programmes at the site indicate a profile consisting of 3 to 4.5 m of slightly calcareous sand, becoming organic rich with shell fragments below 7.5 m. The lower profile consists of pebbly sand grading into gravels.

The secondary aquifer is a semi-confined system which is considered to be in hydraulic connection with the overlying primary aquifer. Interpretation of previous pump test results supports the hypothesis that upward leakage from the Malmesbury Group Aquifer to the primary aquifer can be expected when the water table in the sands is drawn-down to below the piezometric level in the underlying semi-confined aquifer (Murray and Saayman, 2000). These two aquifer systems are generally separated by a weathered (clay) zone in the bedrock. The clay horizon constitutes an aquitard, as it has a low permeability that retards and restricts the vertical movement of groundwater, but does not prevent the movement of the 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 sandstone (greywacke) that weather to produce substantial thicknesses of yellow and / or grey clay. These consolidated meta-sedimentary rocks generally underlie the area surrounding the site (if not intruded by granite and dolerite) and form the semi-impervious base of the Atlantis Aquifer. Alternating successions of greywacke, siltstone and mudstone occur on site, with the beds dipping some 60° to the west. These consolidated sediments are highly weathered along the upper 10 m, with residual clayey silt being observed during the drilling programmes at the site.

The Atlantis Aquifer is an important and significant primary aquifer with two wellfields (Witzand and Silwerstroom) managed by the CoCT. The Witzand Wellfield is situated 3 km north-east of the site and supplies water to the surrounding towns, predominantly to Atlantis. This wellfield is situated in the most productive portion of the Atlantis Aquifer system. The Silwerstroom Wellfield is situated 9.5 km north of the site.

Other than production boreholes at the Witzand and Silwerstroom wellfields, there are many other existing boreholes in the area, including private production and monitoring boreholes (**Figure 2.2**).



srk consulting	NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY LOCATION OF BOREHOLES AT AND SURROUNDING THE DUYNEFONTEIN SITE	Date: 31 10 2012	Compiled by: GOES/FUBM
		Project No. 378677	Fig No. 2.2

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2.1.3 Lithostratigraphy

Atlantis Aquifer

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 listed in **Table 2.2** (Johnson *et al.,* 2006) and shown in **Table 2.3**. The sand thickness varies considerably and reaches a maximum thickness of between 40 and 70 m (Dyke, 1992). Virtually all production boreholes draw groundwater from the medium-grained quartzitic sand horizons of the Springfontyn Formation (Tredoux, 1987), because it is usually the thickest formation present. The Varswater Formation is less significant and its development is limited to old estuarine depressions near the coast (Dyke, 1992). Drilling operations for the assessment indicate that the sand thickness beneath the Duynefontein site ranges from 14 to 27 m.

Malmesbury Group Aquifer

The Malmesbury Group Aquifer is formed by meta-sediments belonging to the Tygerberg Formation of the Malmesbury Group. The formation consists mainly of alternating greyish to medium to fine grained greywacke and phyllitic shale.

The sediments are baked to massive bluish-grey hornfels along their contact with the Cape Granite Suite (not present on-site) and narrow dolerite dykes, both of which have intruded the Malmesbury Group sediments. These dykes, as well as faults in the vicinity of the site, have been delineated by the Council for Geoscience. The bedrock at the site consists of a steeply dipping, interlaminated and bedded succession of greywacke, siltstone and mudstone, with occasional shale interbeds of the Malmesbury Group. Gradational sequences and contacts are characteristic and the beds grade mainly from coarse to fine grained in upward-fining successions.

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 mudstone and siltstone extends to 26 m in some places. The bedrock is brecciated along fault zones, and is intensely jointed and often sheared along such fault planes. Quartz veins, pyrite and clay gouge are ubiquitous in the joints and faults, especially where the wall-rocks of the faults are brecciated.

2.1.4 Hydraulic Properties

Atlantis Aquifer

Pumping tests and double-ring infiltrometer tests have previously been conducted on the Atlantis Aquifer (Van der Merwe, 1980; Bredenkamp and Vandoolaeghe, 1982; Scott, 1989 and Weaver, 1989). Based on these tests, T values for the Atlantis aquifer are 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 Atlantis Aquifer were estimated to be *c*.40 m^2/d (Barker, 1980 and Murray and Saayman, 2000). The Aquarius Wellfield has calculated T values ranging from 15 to 100 m^2/d (Theis method) (Jolly and Hartley, 1996).

Along the coastline at the western edge of the site, a T value of 75 m^2/d was obtained (Fleisher, 1993). Analyses of test pumping results of the boreholes drilled on the site indicate T values ranging from 16 to 140 m^2/d for the upper Atlantis Aquifer (**Table 2.1**).

Table 2.1: Aquifer Parameters of the Upper Atlantis Aquifer Underlying the Duynefontein Site

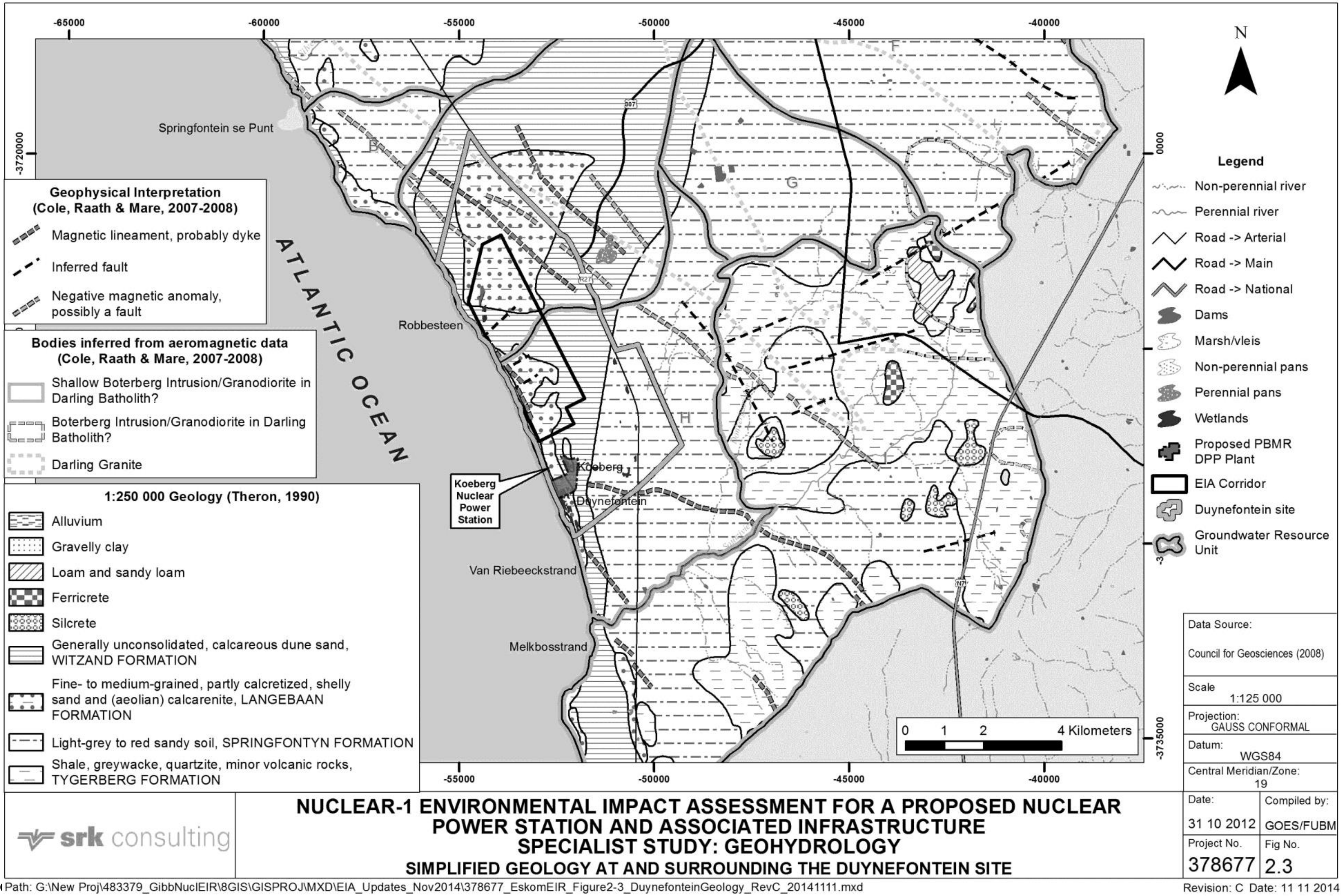
EIR BH No.	Transmissivity T (m^2/d)	Specific Yield (S_y)	Saturation Thickness (m)	Hydraulic Conductivity K (m/day)	Assumed Porosity (%)	Max. Test Yield (L/s)
SRK-KG2	22	2.0×10^{-1}	25.00	0.9	20	5.1
SRK-KG5	140	3.0×10^{-1}	25.00	5.6	20	5.1
SRK-KG8	57	1.1×10^{-1}	21.00	2.7	20	7.0
SRK-KG10	16	2.5×10^{-1}	17.00	0.9	20	5.4
Average	59	2.2×10^{-1}		2.5	20	5.6
Median	40	2.3×10^{-1}		1.8	20	5.3
Note: K was calculated by dividing T by saturation thickness, i.e. aquifer thickness. Aguifer Thickness = BH depth minus water level.						

Hydraulic conductivity for the various formations of the Atlantis Aquifer was found to range between 13 and 35 m/d, with the exception of the Varswater Formation (1 to 3.5 m/d). The average K at the PBMR DPP site was found to be *c*.2.6 m/d (Murray and Saayman, 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 4.0×10^{-3} and 5.0×10^{-3} m/d. Hydraulic conductivity values of 25 m/d were reported for the primary aquifer closer towards Atlantis (Bredenkamp and Vandoolaeghe, 1982). Double ring infiltrometer tests were used to determine vertical K at the artificial recharge basin north-east of the site (Scott, 1989). Based on data derived from the seven such tests, vertical K ranged from 8 to 31 m/d at the recharge basin. Along the coastline at the western edge of the site, a K value of 12 m/d was obtained (Fleisher 1993). Hydraulic conductivity values for the boreholes in the upper primary aquifer range from 0.9 to 5.6 m/d (**Table 2.1**).

Specific yield (S_y) was determined to be between 4.0×10^{-2} (4 per cent) and 5.0×10^{-2} (5 per cent) (Murray and Saayman, 2000 and Bredenkamp and Vandoolaeghe, 1982). Specific yield values of between 1.98×10^{-1} (19.8 per cent) and 2.5×10^{-1} (25 per cent) were determined by Fleisher (1990) for the Atlantis Aquifer. Specific yield values determined from the boreholes range from 1.1×10^{-1} to 3.0×10^{-1} for the primary aquifer (**Table 2.1**), i.e. 11 to 30 per cent and are typical ranges for this type of aquifer.

Table 2.2: The Lithostratigraphy of the Sandveld Group (after Johnson *et al*., 2006)

Formation	Member	Origin	Type	Description	Epoch	Age (Ma)
Witzand		Aeolian	SAND	Fine- to medium-grained, whitish grey to slightly reddish, calcareous, cross-stratified, dune snails, echinoid spicules, forams and comminuted sea shells	Holocene	0.01 to 0
Springfontyn		Aeolian	SAND	Fine- to medium-grained, quartzitic sand, muddy and peaty in places	Pleistocene to Holocene	1.8 to 0.01
Langebaan		Aeolian	CALCAREOUS SANDSTONE	Cross-bedded, fine- to medium-grained, with calcrete layers	Late Pliocene to Late Pleistocene	2 to 0.2
Velddrif		Shallow marine	GRAVEL and SAND	Shelly and pebbly, cross-bedding	Plio-Pleistocene to Late Pleistocene	1.8 to 0.2
Varswater	Muishond Fontein	Estuarine / shallow-marine	SAND	Phosphatic, quartz-sand	Miocene to Pliocene	23 to 5
	Langeberg	Estuarine / shallow-marine	SAND	Non-phosphatic, carbonaceous clay and lignite lenses	Miocene to Pliocene	23 to 5
	Konings Vlei	Shallow-marine	GRAVEL	Pebbles and cobbles	Miocene to Pliocene	23 to 5
	Langeenheid	Estuarine	SAND	Argillaceous (clayey sand / silt)	Middle Miocene	14
Elandsfontyn		Fluvial	SAND and GRAVEL	Angular clasts, carbonaceous clay and lignite lenses	Early to Middle Miocene	23 to 14


Springfontein se Punt
Robbesteen
Koeberg Nuclear Power Station
Koeberg
Duynefontein
Van Riebeeckstrand
Melkbosstrand
ATLANTIC OCEAN
Geophysical Interpretation (Cole, Raath & Mare, 2007-2008)
Magnetic lineament, probably dyke
Inferred fault
Negative magnetic anomaly, possibly a fault
Bodies inferred from aeromagnetic data (Cole, Raath & Mare, 2007-2008)
Shallow Boterberg Intrusion/Granodiorite in Darling Batholith?
Boterberg Intrusion/Granodiorite in Darling Batholith?
Darling Granite
1:250 000 Geology (Theron, 1990)
Alluvium
Gravelly clay
Loam and sandy loam
Ferricrete
Silcrete
Generally unconsolidated, calcareous dune sand, WITZAND FORMATION
Fine- to medium-grained, partly calcretized, shelly sand and (aeolian) calcarenite, LANGEBAAN FORMATION
Light-grey to red sandy soil, SPRINGFONTYN FORMATION
Shale, greywacke, quartzite, minor volcanic rocks, TYGERBERG FORMATION
Legend
Non-perennial river
Perennial river
Road -> Arterial
Road -> Main
Road -> National
Dams
Marsh/vleis
Non-perennial pans
Perennial pans
Wetlands
Proposed PBMR DPP Plant
EIA Corridor
Duynefontein site
Groundwater Resource Unit
0 1 2 4 Kilometers
-65000 -60000 -55000 -50000 -45000 -40000
-3720000 -3735000
Data Source: Council for Geosciences (2008)
Scale 1:125 000
Projection: GAUSS CONFORMAL
Datum: WGS84
Central Meridian/Zone: 19
Date: 31 10 2012
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Project No. 378677
Fig No. 2.3
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SPECIALIST STUDY: GEOHYDROLOGY
SIMPLIFIED GEOLOGY AT AND SURROUNDING THE DUYNEFONTEIN SITE
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Malmesbury Group Aquifer

The Malmesbury Group Aquifer, which is a secondary, i.e. fractured, aquifer, is highly anisotropic and aquifer parameters vary significantly across the site and regionally. Work done for the PBMR DPP site indicated a T value of 30 m^2/d (Murray and Saayman, 2000), probably representing 'fracture' T. Test pumping analysis for the boreholes indicate T values ranging from 5 to 180 m^2/d for this aquifer (see **Table 2.3**).

Table 2.3: Aquifer Parameters of the Malmesbury Aquifer Underlying the Duynefontein Site

EIR BH No.	Transmissivity T (m^2/d)	Storativity S	Aquifer Thickness D (m)	Calculated Hydraulic Conductivity K (m/day)	Max Test Yield (L/s)	Recommended Sustainable Yield (L/s)	Aquifer Type
SRK-KG1	19.00	1.0×10^{-4}	56	0.3	15.00	1.00	Fractured
SRK-KG3	5.00	9.0×10^{-4}	53	0.1	4.50	0.30	Matrix
SRK-KG4	70.00	1.4×10^{-4}	42	1.7	15.00	6.00	Fractured
SRK-KG6	31.00	1.9×10^{-4}	37	0.8	10.25	2.40	Fractured
SRK-KG7	113.00	3.0×10^{-4}	37	3.1	14.00	4.50	Fractured
SRK-KG9	180.00	2.9×10^{-4}	30	6.0	5.10	4.00	Fractured
Average	69.67	1.2×10^{-4}		2.0	10.64	3.03	
Median	50.50	1.1×10^{-4}		1.3	12.13	3.20	

Aquifer thickness = Deepest water strike minus the rest water level.

Packer test results for the boreholes in the lower bedrock aquifer indicate K values ranging from 0.1 to 6.0 m/d (see **Table 2.3**).

Storage values determined from the boreholes range 1.0×10^{-4} to 2.9×10^{-4} for the bedrock aquifer (**Table 2.3**), indicating confined to semi-confined conditions. These values compare with those obtained by other investigations (Murray and Saayman, 2000)

2.1.5 Borehole Yields

Atlantis Aquifer

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 (Fraser and Weaver, 1996). Boreholes drilled into sands along the areas north-east of the site, at the planned regional landfill facility for the CoCT, were reported to yield in excess of 5 L/s (Parsons, 2002). Borehole yields in the range of 0.5 to 5 L/s are common in the sands underlying the existing KNPS. Two boreholes drilled during 1991 by SRK along the northern boundary of the site yielded 1.7 and 4.2 L/s (Rosewarne, 1989 and Rosewarne, 1995). Ten boreholes drilled to depths of between 25 and 33 m along the Aquarius Wellfield yielded between 2 and 6 L/s (Jolly and Hartley 1996). Maximum test pumping yields obtained for the four boreholes drilled into the primary aquifer ranged from 5.1 to 7 L/s (**Table 2.3**).

Previous aquifer tests conducted on boreholes drilled into the primary aquifer showed a stabilisation of groundwater level drawdown at sea level or just above, when pumping such boreholes at *c*.2.5 L/s (Saayman and Weaver, 2001).

Malmesbury Group Aquifer

It is generally accepted that boreholes drilled into the Malmesbury Group Aquifer yield considerably less than the primary aquifer, i.e. <2 L/s. This was supported by an assessment of the Malmesbury Group Aquifer during 2001 (Meyer, 2000 and Meyer, 2001). Exploration boreholes drilled in the shale at the planned CoCT regional landfill facility south of Atlantis yielded between 0.1 and 0.3 L/s (Parsons and Flanagan, 2006).

During exploratory drilling at the PBMR site, a fracture yielding in excess of 12 L/s was encountered (Saayman and Weaver, 2001). As part of the groundwater assessment, six boreholes drilled into the Malmesbury Group Aquifer recorded blow yields of between 2 and 12 L/s (**Table 2.3**), with a mean yield of *c*.5 L/s (Flanagan, 2008a). These consistently high yields encountered in the secondary, fractured aquifer system are uncommon for such aquifers in the region. Based on the pumping test results, the Malmesbury Group Aquifer may provide an additional source of groundwater to the surrounding areas. However, pumping at high rates along the coast is unlikely to be feasible due to the increased potential for saline intrusion.

2.1.6 Recharge

Tritium (^3H) content of groundwater can provide a qualitative indication of recharge. There are two main sources of ^3H in the groundwater. It is naturally produced at low levels in the upper part of the atmosphere (*c*.10 to 20 km above the earth's surface) when cosmic rays collide with air molecules (cosmogenic processes). ^3H has also been largely produced from the atmospheric testing of hydrogen (atomic) bombs that began at the end of 1952 (nuclear fallout-produced), with the release of ^3H peaking in 1963.

^3H concentrations are given as TU (tritium units), equivalent to a concentration of 10^{-18} (where one TU corresponds to one ^3H atom to 10^{18} hydrogen atoms). Other disciplines in which tritium is measured, may use the specific radioactivity in Bq (Becquerel) or mBq, related to TU by:

1 TU = 0.118 Bq/L of water or 1 Bq/L = 8.47 TU

Tritium has a half-life of 12.43 years. This radioactive isotope of hydrogen was present in rainwater up to the middle 1950s at a maximum concentration around 60 TU in 1964. Since then, levels have been declining worldwide (Verhagen, 1984). Tritium is found in trace amounts in groundwater throughout the world (USNRC, 2006).

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 after 1952. Pre-1952 groundwater contains ^3H that is not detectable by normal procedures while post-1952 groundwater would contain relatively high levels of ^3H. Tritium concentrations in groundwater have been interpreted as follows (Mazor, 1991):

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

Atlantis Aquifer

Estimates of recharge (as a percentage of rainfall) in the vicinity of the site have previously been made by Bredenkamp and Vandoolaeghe (1982), Vandoolaeghe and Bertram (1982), Bertram *et al.*, (1984), Fleisher (1990) and Fleisher and Eskes (1992). Average recharge was estimated to be between 10 and 30 per cent of mean annual precipitation (MAP).

A recharge factor of 25 per cent of MAP was derived for the area surrounding the Silwerstroom Wellfield, by using a water-balance approach to analyse groundwater monitoring information collected between 1978 and 1982 (Bredenkamp and Vandoolaeghe, 1982).

Fleisher and Eskes (1992) determined natural recharge near the site to be 23 per cent for vegetated areas and 42 per cent for non-vegetated areas.

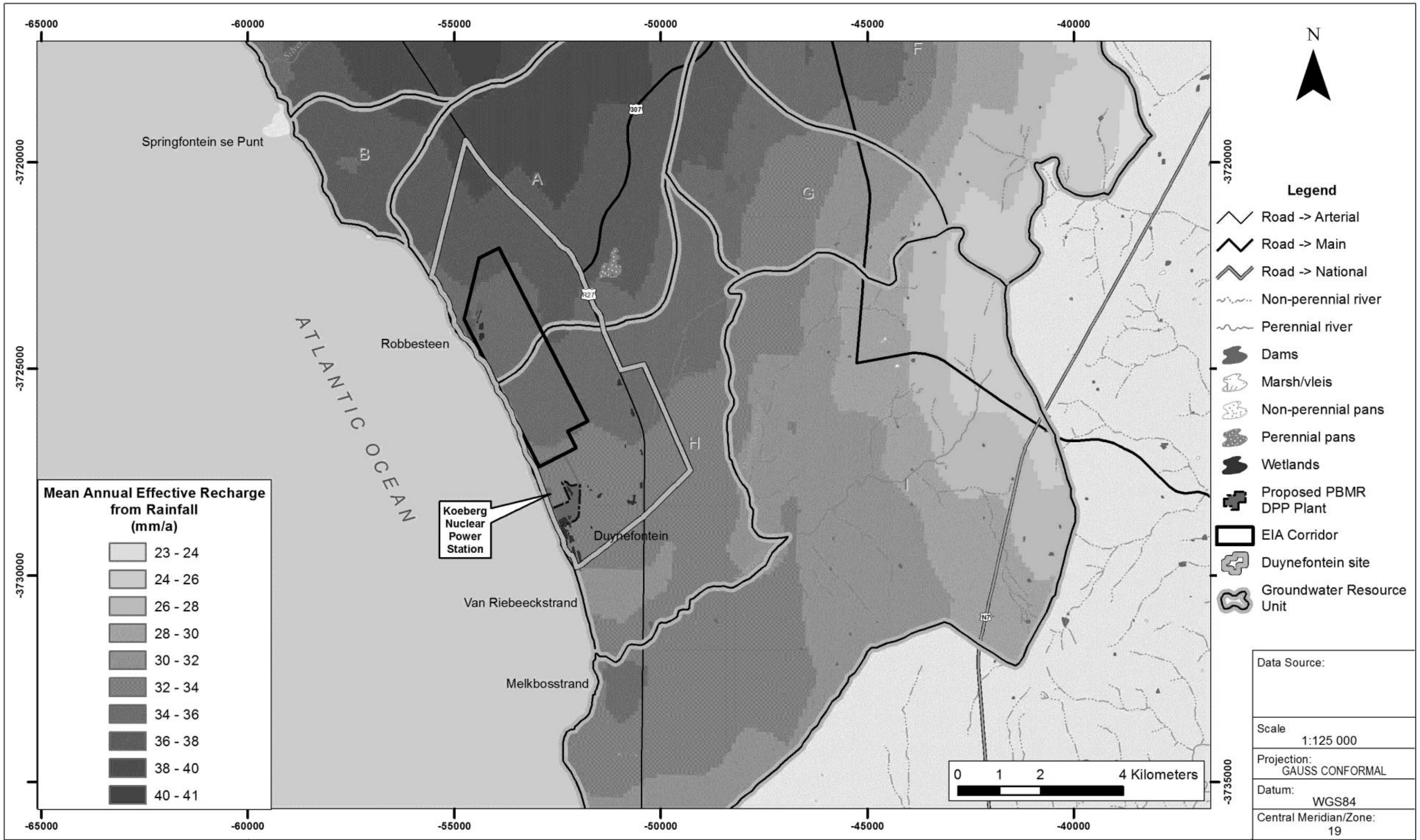
Significant ^{3}H concentrations (>1 TU) in the primary aquifer indicate a fairly dynamic system with groundwater in the aquifer being some 10 to 20 years old.

The GRA-II data-set (DWAF, 2005) provides an 'average' rainfall-recharge factor for the G21B quaternary catchment of 15.4 per cent using the Chloride Mass Balance (CMB) approach (**Figure 2.4**). The recharge in the Duynefontein GRU was estimated to be 15 per cent of MAP (Woodford, 2007).

Due to the unconfined nature of the upper sediments, recharge takes place over the entire area. Following a review of all available recharge estimates for this assessment, a site recharge figure of 15 per cent is considered to be representative.

Malmesbury Group Aquifer

An interpretation of the previous results shows that the groundwater regime is less dynamic in the lower-lying secondary aquifer than in the primary aquifer, which indicates that negligible or no recharge to the Malmesbury Group aquifer occurs in the vicinity of the site. The deeper aquifer is recharged further inland, possibly several kilometres east of the site in areas where the Malmesbury Group outcrops.



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SPECIALIST STUDY: GEOHYDROLOGY
RECHARGE AT AND SURROUNDING THE DUYNEFONTEIN SITE

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2.1.7 Depth to Groundwater

Atlantis Aquifer

Seasonal rainfall variation does not significantly affect the groundwater flow direction or groundwater levels at the site. The influence of tides may impact on temporal variations in groundwater levels. Based on previous observations, groundwater levels west of the Koeberg 900 MWe PWR Units 1 and 2 fluctuated by some 0.55 m during construction of the units and by 0.70 m within the foundation area of the units (Dames and Moore, 1975a and Dames and Moore, 1975b).

Monitoring data of boreholes in close proximity to the site since 1985 shows no indications 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. Seasonal trends are evident, as is the short duration influences of pumping. Monitoring data for the Atlantis Aquifer are available from 1963, but these boreholes are located further away from the site, and have therefore not been included in the assessment of monitored groundwater level data.

The water table ranges between 2 and 5 mbgl. The depth to groundwater mimics surface topography. Seasonal and tidal impacts are the dominant factors influencing local groundwater level fluctuations. The Aquarius (1.5 km north-east of the site) and Witzand wellfields are the closest groundwater abstraction areas to the site. Numerical modelling of the effect of abstraction from the Aquarius Wellfield on groundwater levels showed that there would be no significant impacts at either the KNPS or at the site (Du Toit *et al.,* 1995).

Monitoring of groundwater levels within the boreholes since February 2008 using data loggers indicates only minor variation in groundwater levels over four years of data collection (**Figure 2.5**). Borehole KG10 represents the water level in the Primary Aquifer and depth to groundwater is between 1 to 2 mbgl (12.6-13.7 mamsl). Similarly, borehole G33444 represents the water level in the primary aquifer further inland with depth to groundwater ranging between 3.5 and 4 mbgl. At boreholes D-SW7-MR1, -MR2 and -MR3, which are located next to the dune-slack wetland SW7, the depth to groundwater ranges from 1.0 to 1.5 mbgl. Depth to groundwater at the wetland piezometer D-SW7-WP1 ranges from 0-0.2 mbgl. At piezometers D-WP2 and D-WP3, which are located in one of the coastal wetlands (SW1) south of the KNPS, water level ranges from 0 mbgl in the wet season to 1.0 mbgl in the dry season.

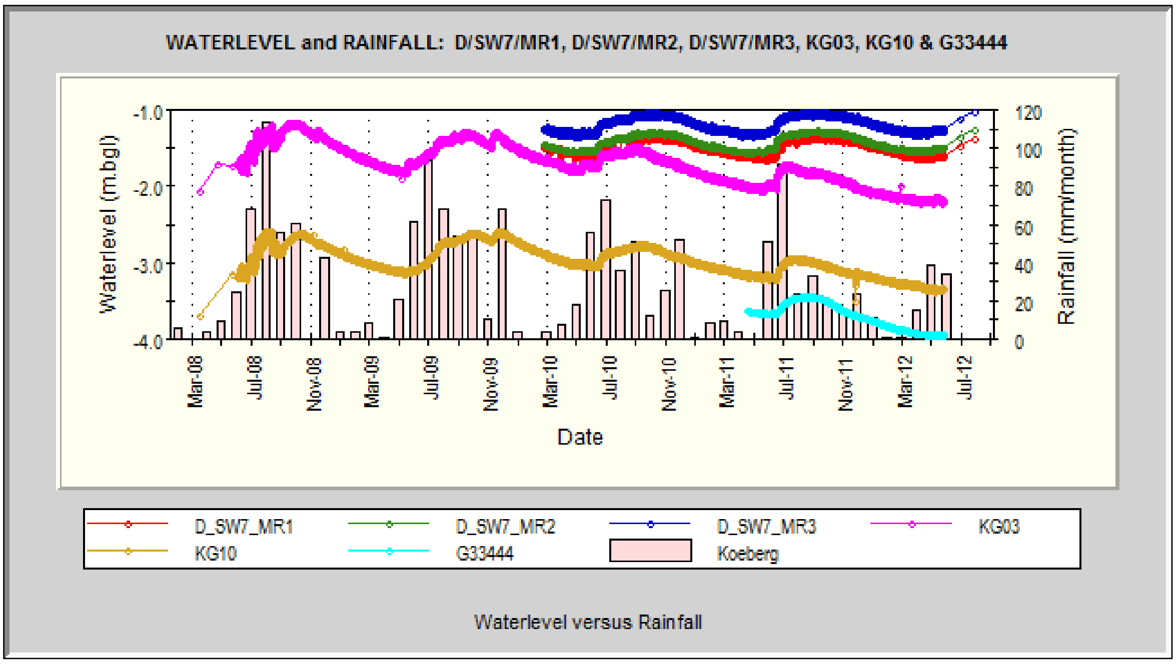
Malmesbury Group Aquifer

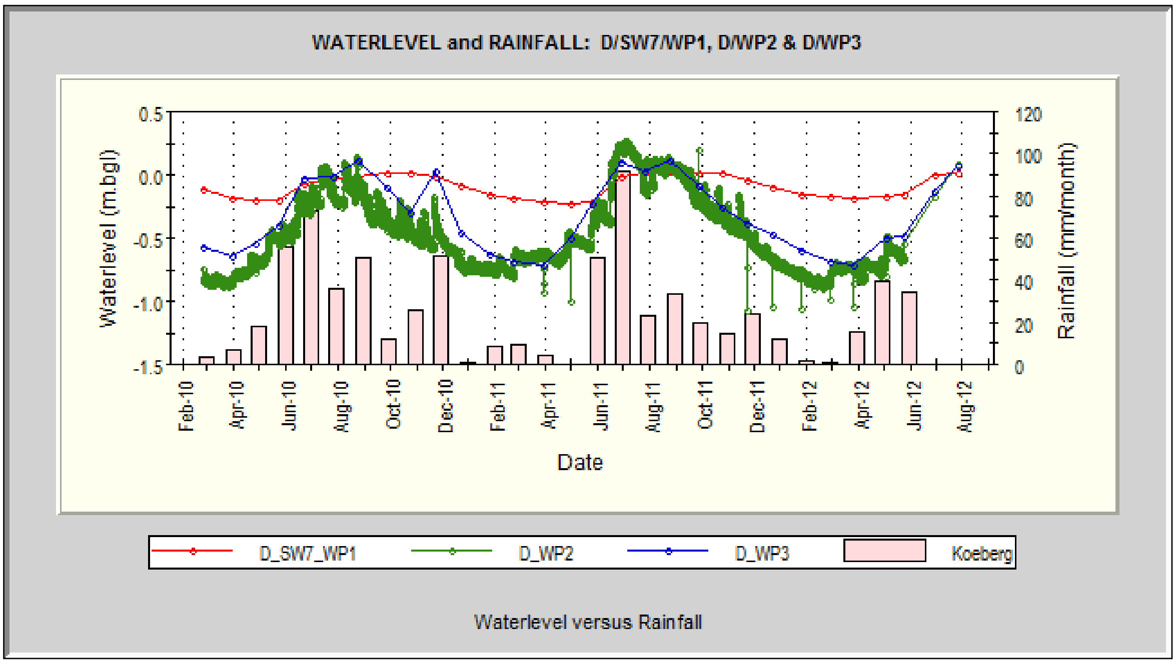
Measurement of the piezometric level at the PBMR DPP site indicates that levels vary between 3.4 and 4.3 mbgl (Murray and Saayman, 2000).

Groundwater levels measured in the deeper boreholes (i.e. secondary aquifer) and that measured in the shallow boreholes (i.e. primary aquifer) at the PBMR DPP site differ by <0.5 m (Murray and Saayman, 2000). This supports the contention that the Malmesbury Group Aquifer is a semi-confined system and the seasonal groundwater level variation is likely to be insignificant.

Monitoring of groundwater levels within the boreholes since February 2008 using data loggers indicates only minor variation in groundwater levels over four years of data collection (**Figure 2.5**). Borehole KG03 represents the water level in the Malmesbury Group Aquifer and depth to groundwater is between 1.1 to 2.2 mbgl (12.5 to 14 mamsl).

Figure 2.5: Groundwater Level Fluctuation in Boreholes (top) and Wetland Piezometers (bottom) at the Duynefontein site





2.1.8 Direction of Groundwater Flow

Atlantis Aquifer

A regional groundwater level contour map was compiled using data collected from previous monitoring carried out by the CSIR and that collected during a hydrocensus conducted during August and September 2004 (Parsons and Flanagan, 2006). From this it was interpreted that groundwater flows in a south-westerly direction towards the coast. Using the data collected during this Project, a detailed site groundwater level contour map was compiled (**Figure 2.6**). The figure shows groundwater contours constructed from measured rest water levels and indicates the direction of groundwater flow, which agrees with the above findings.

According to the results of previous numerical models, even at high abstraction rates at the Aquarius Wellfield, the resulting maximum zone of depression will not reach the site (Murray and Saayman, 2000). The direction of groundwater flow will only be reversed due to over-abstraction at the wellfields up-gradient of the site. Based on information derived from the models, it is not likely that contamination occurring at the site can impact on the major aquifer systems up-gradient, at least under liquid effluent release scenarios. The receiving environment / downstream receptor of any contamination will be the shore zone / ocean. This excludes air emissions.

Malmesbury Group Aquifer

The interpreted direction of groundwater flow, based on field measurements, is also in a south-westerly direction towards the coast (**Figure 2.6**).

2.1.9 Hydraulic Gradient

Atlantis Aquifer

The hydraulic gradient across the site has been determined from **Figure 2.6** and is *c*.0.0125 rising to *c*.0.025 closer to the coast. Groundwater therefore flows under a relatively low gradient towards the coastline.

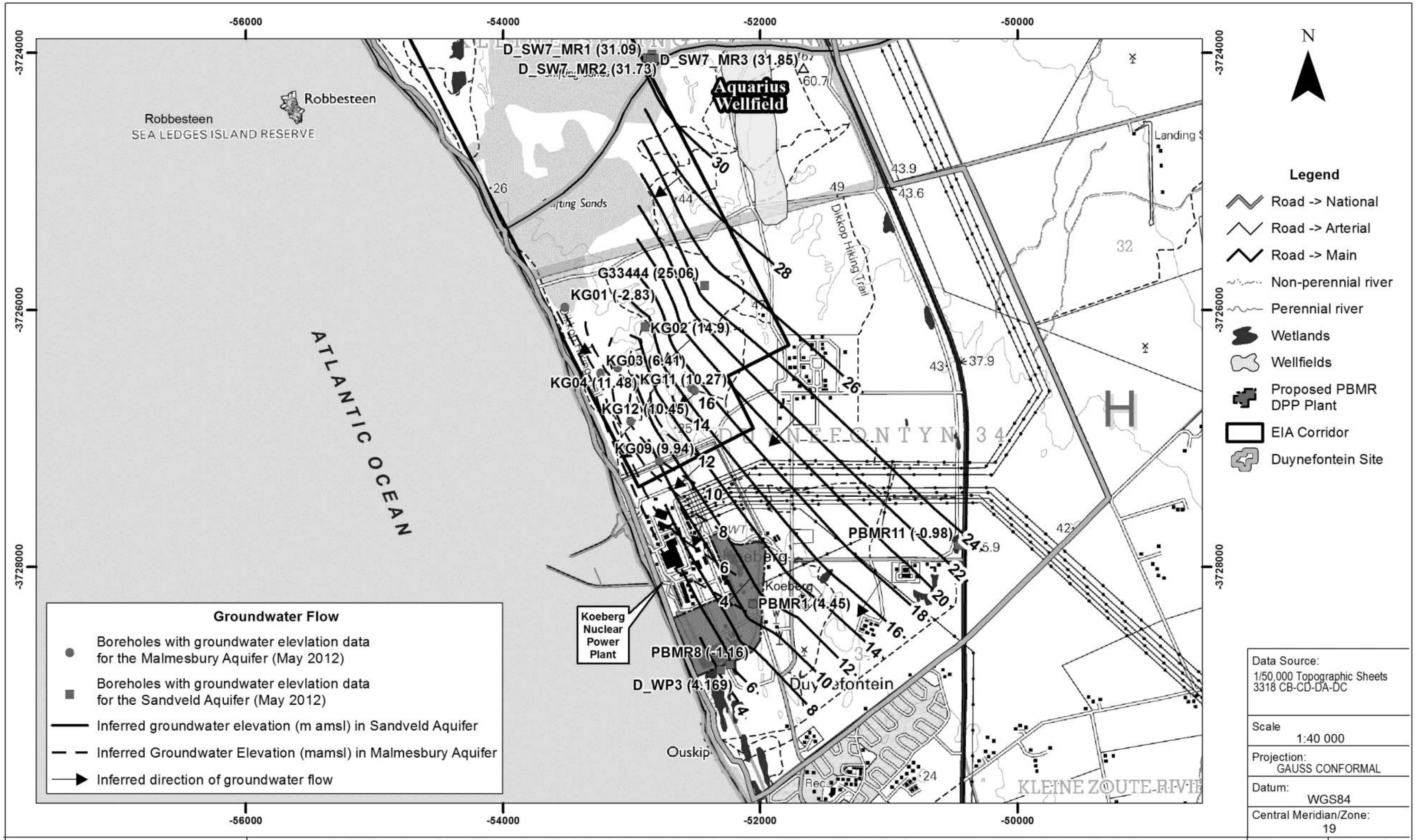
Malmesbury Group Aquifer

A similar gradient exists in this aquifer.

2.1.10 Rate of Groundwater Flow

Atlantis Aquifer

Groundwater was calculated to flow towards the coast at a rate of *c*.2.6 m/d, which indicates a relatively quick migration across the site.



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SPECIALIST STUDY: GEOHYDROLOGY
GROUNDWATER ELEVATION AND INFERRED DIRECTION OF GROUNDWATER FLOW AT AND SURROUNDING THE DUYNEFONTEIN SITE

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Malmesbury Group Aquifer

The rate of flow through the Malmesbury Group Aquifer is estimated to be *c*.0.003 m/d. This slower flow rate is a result of the mostly lower T. Flow rates along individual fractures could be an order of magnitude or higher.

2.1.11 Groundwater Quality

Atlantis Aquifer

Regional groundwater quality of the Atlantis Aquifer was discussed in detail by Fleisher (1990). The groundwater of this aquifer was classified as Class A type (EC <70 mS/m) (Vandoolaeghe and Bertram, 1982). The groundwater is generally of a sodium (Na) - chloride (Cl) type, but younger groundwater in the vicinity of the site shows a calcium (Ca) - bicarbonate (HCO_3) character (Parsons, 1999). Interpretation of groundwater quality data collected at the site of the PBMR DPP site confirms that groundwater quality in the vicinity of the site has a Na-Cl character, as is typical of groundwater in coastal environments. Based on monitoring data and previous investigations, groundwater in close proximity to the site also shows a magnesium (Mg) - sulfate (SO_4) and MgCl character, as shown in the Durov diagram below (**Figure 2.7**).

Samples were subsequently collected from early 2010 for chemical analysis as part of the extended monitoring programme. The results of these analyses are plotted in Piper diagrams in **Figure 2.8**. The groundwater samples for the Malmesbury Group Aquifer show a NaCl signature whilst those for the Atlantis Aquifer near the dune slack wetland (D SW7 MR1 to MR3) show a stagnant signature (enriched in SO_4 and/or CaCl) due to evaporation of the shallow groundwater in the vegetated wetland. The wetland water samples at D/WP2 & 3, which are near the coast, all show a NaCl-type water whilst the water from the dune-slack wetland at D/WP1 shows a stagnant signature similar to the nearby boreholes.

Based on field measurements, EC at the site ranges between 85 and 215 mS/m, while at the Aquarius Wellfield, it ranges from 135 to 200 mS/m (Jolly and Hartley, 1996). Some 18 wellpoints were previously installed along the coastline (along the western boundary of the site), and groundwater EC levels at these wellpoints ranged from 65 to 150 mS/m (Fleisher, 1993). Groundwater samples from four boreholes and wellpoints (E08, GCS1, PBMR-BH and TW2) were collected in close proximity to the site during the hydrocensus, and EC levels in these samples ranged from 100 to 250 mS/m. Groundwater quality monitoring data are available for the Witzand Wellfield indicates that EC levels vary between 50 and 250 mS/m in the vicinity of the site (**Figure 2.9**).

According to the DWAF *Quality Guidelines for Domestic Water Supplies* (DWAF, 1998), the above EC ranges are classified as ideal to marginal for drinking purposes and represents slightly saline conditions. The DWAF EC classes are given in **Table 2.4**.

Figure 2.7: Hydrochemical Character of Groundwater near to the Duynefontein Site (borehole names in legend)

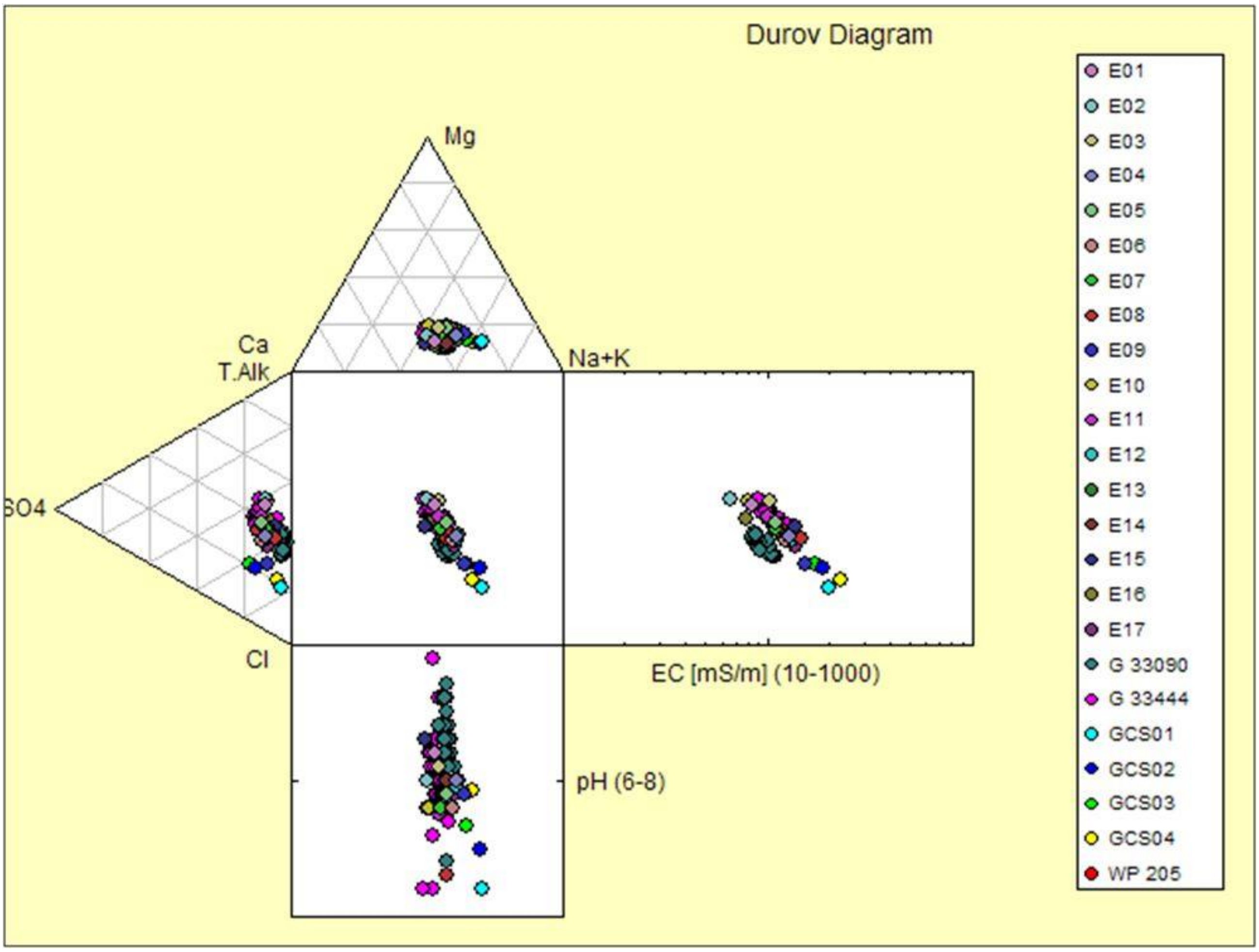


Table 2.4: EC Guideline (after DWAF, 1998)

Range (in mS/m)	Class	Comment
< 70	Ideal	No effects
70 - 150	Good	Insignificant effect on sensitive groups
150 - 370	Marginal	Slight possibility of salt overload in sensitive groups
370 - 520	Poor	Possible health risk to all individuals
> 520	Completely unacceptable	Increasing risk of dehydration

Figure 2.8: Hydrochemical Character of Groundwater at the Duynefontein Site (Malmesbury Aquifer SSR Boreholes (top left), the Sandveld Aquifer SSR Boreholes (top right), the Sandveld Aquifer Wetland Boreholes (bottom left) and the Wetland Piezometers (bottom right)

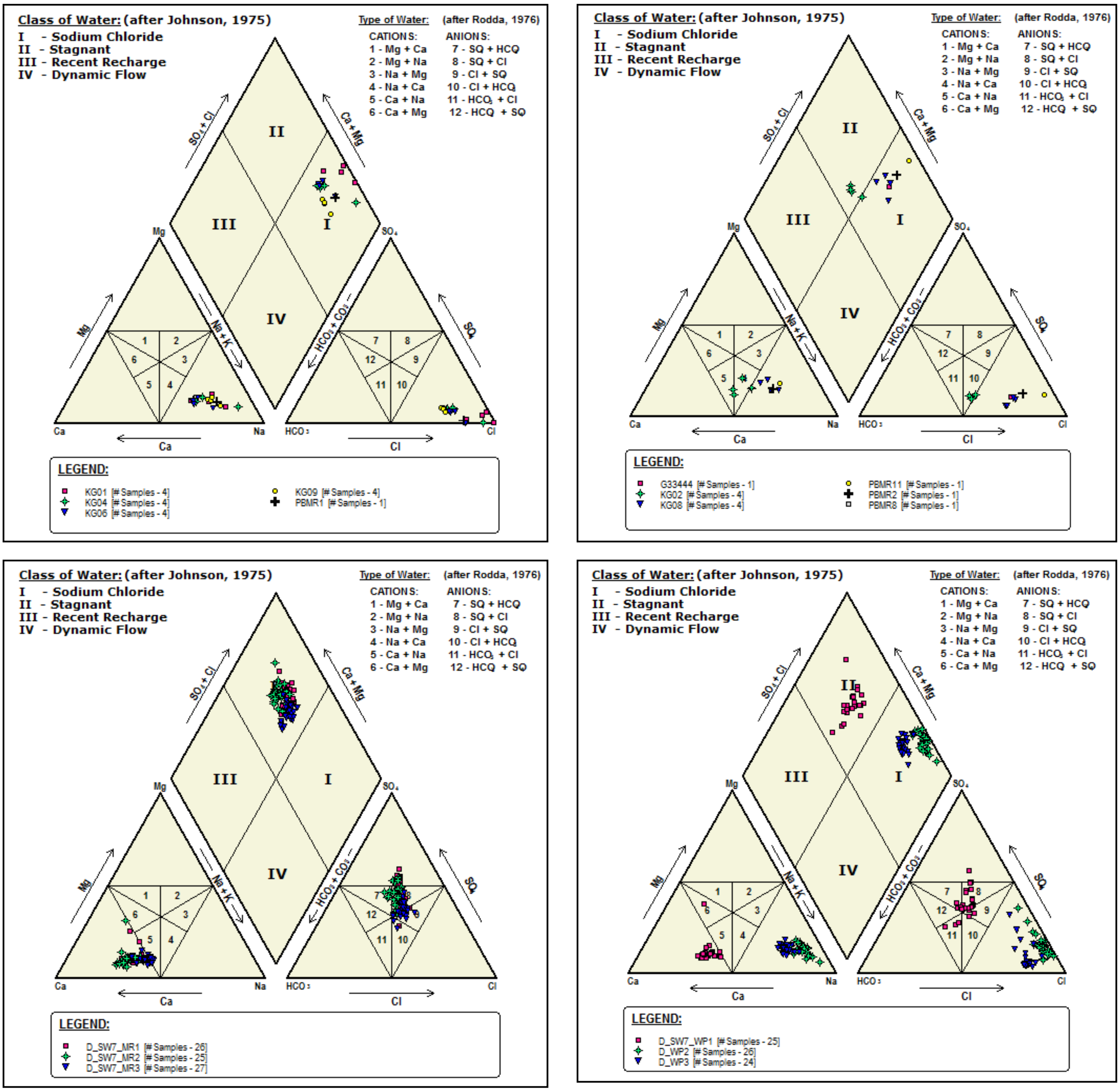
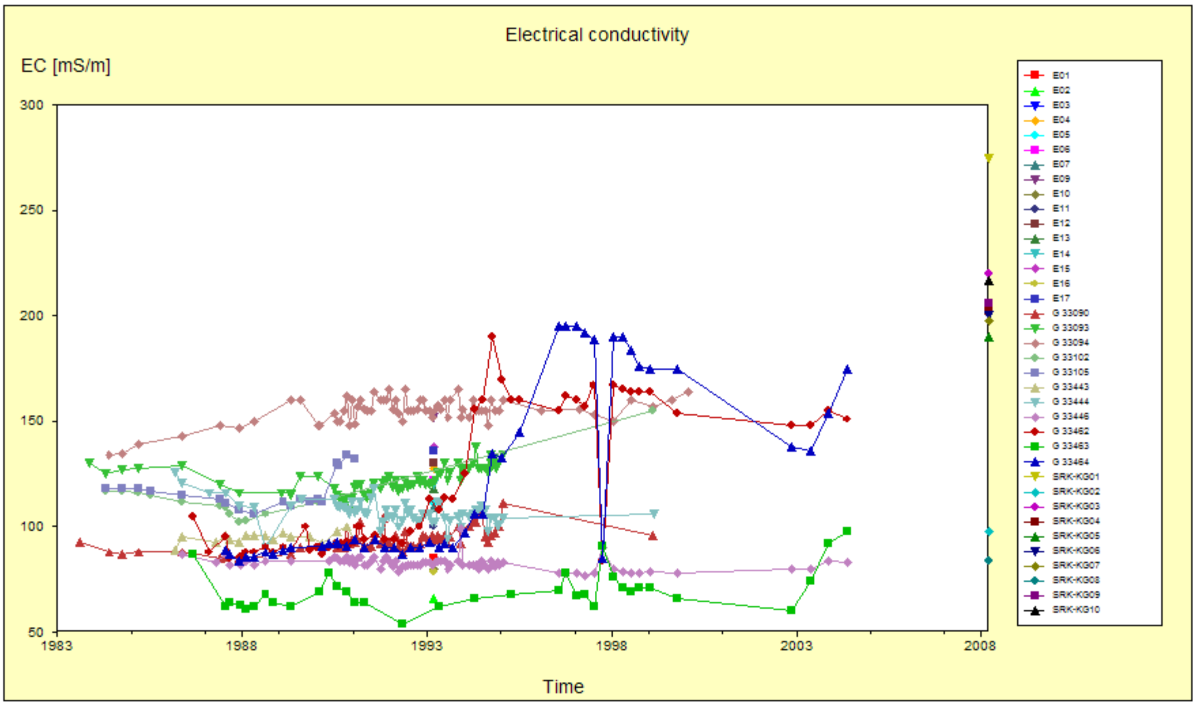


Figure 2.9: Monitored Groundwater EC Data Since 1983 (borehole names in legend)



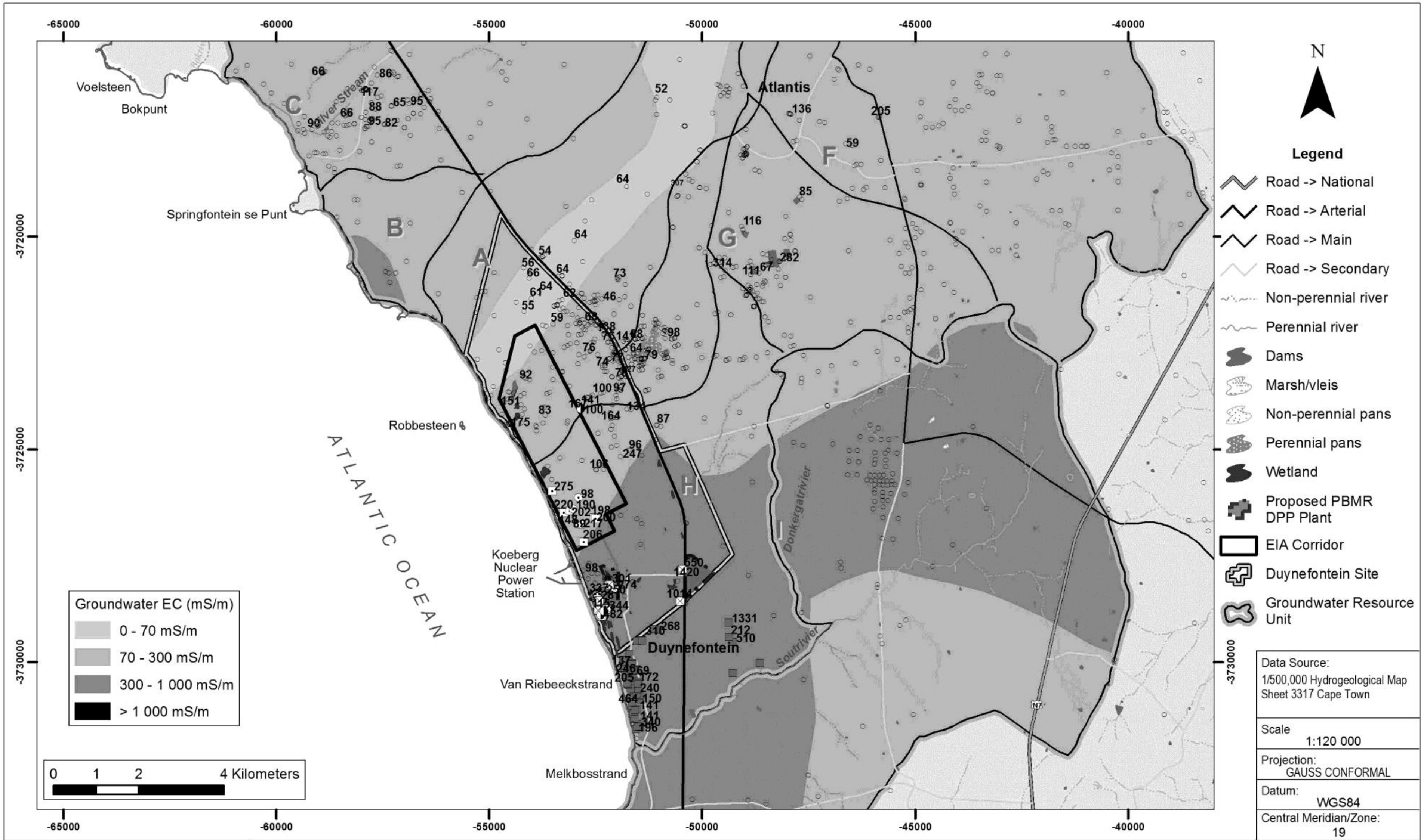
The SABS (2006) specifies the quality of acceptable drinking water and describes two classes of drinking water. The SABS EC classes are listed in **Table 2.5**.

- Class I – is considered to be acceptable for lifetime consumption, and is the recommended compliance limit; and
- Class II – is considered to represent drinking water for consumption for a limited period. This class specifies a water quality range that poses an increasing risk to consumers dependent on the concentration of the determinand within the specified range. The limits for the consumption of Class II water are based on the consumption of 2 L/d of water by a person of mass 70 kg over a period of 70 yrs (SABS, 2006).

Table 2.5: EC Requirements (after SANS, 2006)

Range (in mS/m)	Class	Comment
< 150	Class I	Recommended operational limit
150 to 370	Class II	Maximum allowable for limited duration; Maximum water consumption period is 7 yrs

The quality of the groundwater is a direct result of the closeness 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 (**Figure 2.10**).



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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
GROUNDWATER QUALITY (IN TERMS OF EC) AT AND SURROUNDING THE DUYNEFONTEIN SITE

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31 10 2012	GOES
Project No.	Fig No.
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Isotopes of oxygen (O) and hydrogen (H) are ideal geochemical tracers of groundwater since their concentrations are not subject to changes by interaction with the aquifer material. Once underground and removed from zones of evaporation, the isotope ratios are conservative and only affected by mixing. Precipitation mixing in the unsaturated zone results in smoothing of the isotropic variations. Groundwater in the saturated zone thus has a composition corresponding to the mean isotropic composition of infiltration in the area. This may differ slightly from the mean isotropic precipitation due to the fact that not all precipitation during the year infiltrates in the same proportion.

Stable environmental isotopes deuterium (δD) and oxygen-18 ($\delta^{18}O$) were previously analysed for (Levin, 2001). These analyses were undertaken to determine the origin and age of groundwater at the PBMR DPP site and provide an estimate of the degree of mixing of groundwater in the primary and secondary aquifers and indicate the rate of groundwater flow. Based on the results, $\delta^{18}O$ concentrations in the adjacent 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 $\delta^{18}O$ concentration is related to evaporation processes, and the values represent mixed groundwater (Levin 2001). The δD results confirmed the evaporated nature of groundwater at the shallow wellpoints.

The four boreholes sampled for this assessment in January 2008 were analysed for ^3H, δD and $\delta^{18}O$ (**Table 2.6**). Groundwater from the Aquarius Wellfield (GCS1) has a ^3H concentration of 0.2 TU, while groundwater along the coast (along the western boundary of the site; E08) has a concentration of 1.9 TU. However, samples collected at the KNPS and PBMR DPP sites have ^3H concentrations of 3.6 and 4.2 TU, respectively.

Table 2.6: Summary of Hydrocensus Stable Isotope and Tritium Analysis

Borehole Name	Deuterium	Oxygen-18	Tritium	
	δD	**$\delta^{18}O$**	**TU**	**± ****
E08	-19.0	-3.78	1.9	0.3
GCS1	-21.3	-4.25	0.2	0.3
PBMR-BH	-18.4	-3.81	4.2	0.4
TW2	-9.5	-2.18	3.6	0.4

** These are the counting statistic for a sample counted for a total of 8 hrs

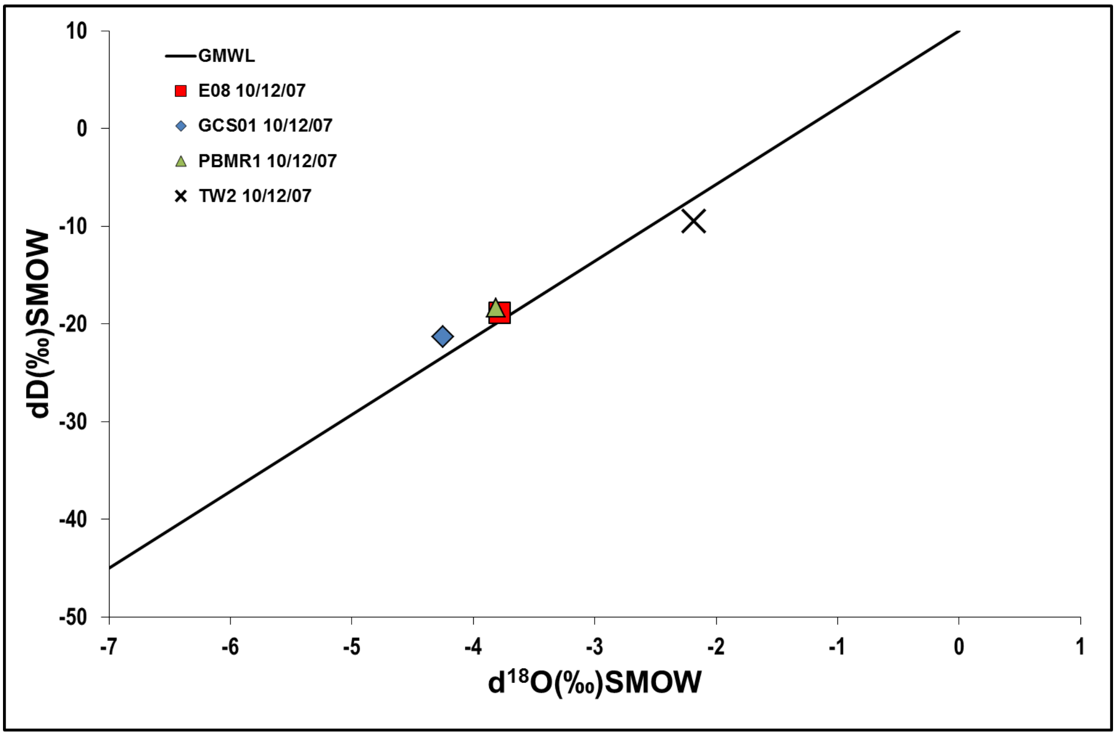
A δD versus $\delta^{18}O$ data plot relative to the global meteoric water line (GMWL) is shown in **Figure 2.11**. The GMWL provides an important key to the interpretation of δD and $\delta^{18}O$ data. Water with an isotopic composition falling on the GMWL is assumed to originate from the atmosphere and therefore has not been affected by 'artificial' isotopic processes (Domenico and Schwartz, 1990). 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.

Subsequently, as part of an extended monitoring programme, samples were collected on a regular basis from monitoring boreholes on the site and analysed for ^3H, δD and $\delta^{18}O$. The δD and $\delta^{18}O$ results are plotted on **Figure 2.12**, whilst the ^3H variation is shown in **Figure 2.13**.

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 warm regions) (Craig, 1961). The cluster above the GMWL indicates uniform and localised direct recharge. Borehole

TW2 is located on the shoreline, which may have resulted in the slight enrichment of $\delta^{18}O$.

Figure 2.11: Analysis of $\delta^{18}O$ versus δD for the Duynefontein Site (Hydrocensus boreholes)



The isotopic signature of the groundwater and surface water samples analysed to date are shown in **Figure 2.12**. The groundwater samples plot as a cluster showing slight ^{18}O enrichment close to the global meteoric water line (GMWL), measured with respect to standard mean ocean water, SMOW) relative to the GMWL, which can be attributed to evaporation prior to infiltration. The wetland piezometer and wetland borehole water shows isotopic enrichment due to evaporation losses.

The ^{3}H values of groundwater from the monitoring boreholes on the site do not show clear trends, except for KG02, which shows a decline in concentration over time.

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 is aggressive to ordinary concrete when present in concentrations >200 mg/L, ranges from 44 to 77 mg/L and the risk to foundations is therefore considered to be low. The Larson-Skold corrosion indices 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 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(s) design.

Figure 2.12: Analysis of δ 18O versus δD for the Duynefontein site (Wetland Boreholes (top left), Wetland Piezometers (top right), SSR Malmesbury Aquifer Boreholes (bottom left) and SSR Sandveld Aquifer Boreholes (bottom right))

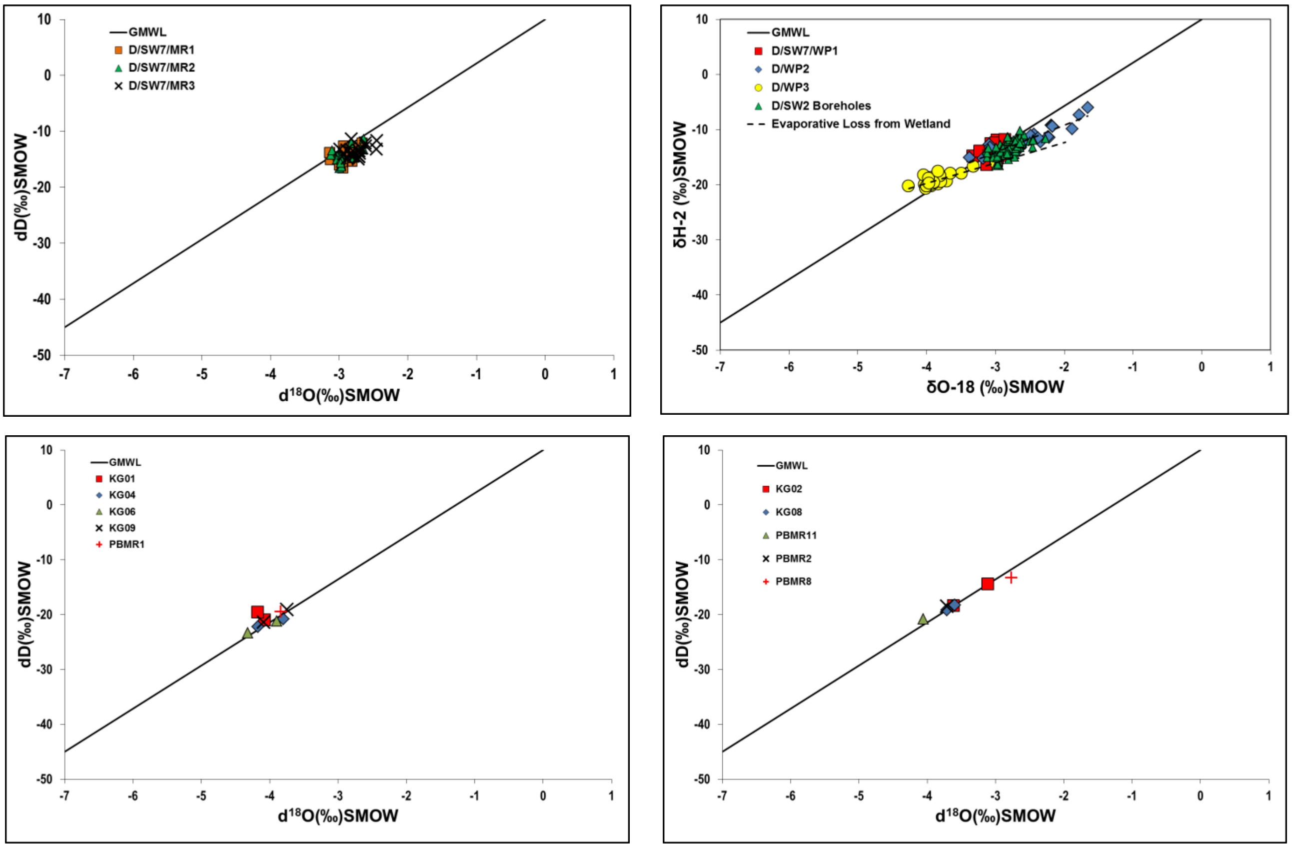
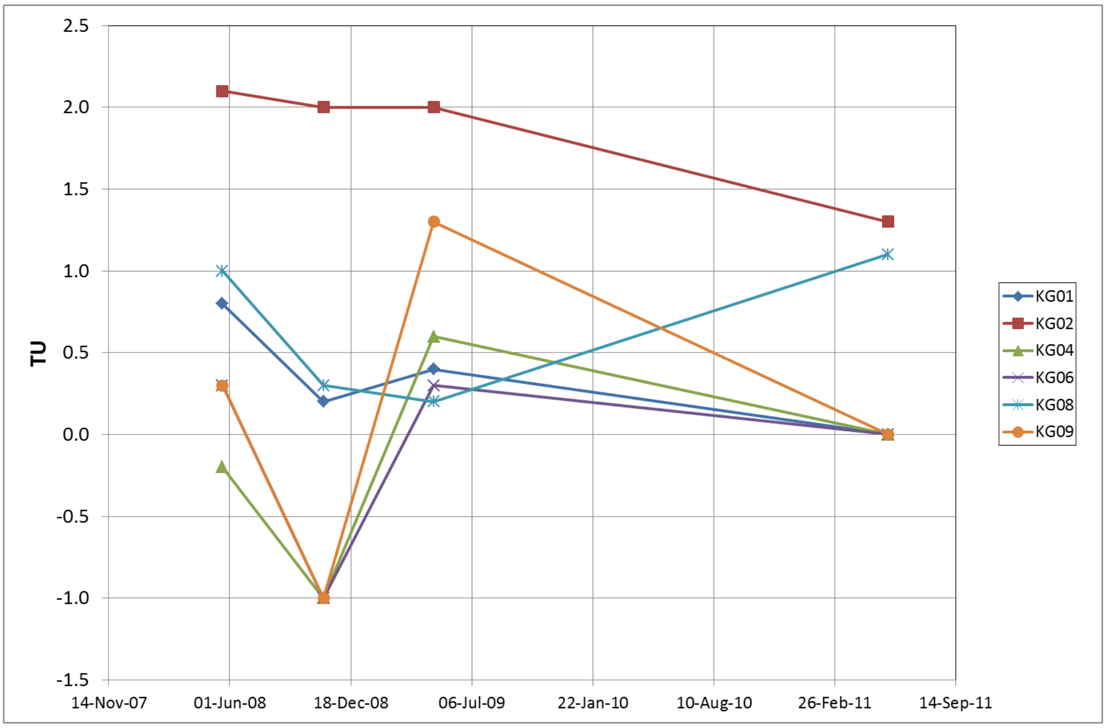


Figure 2.13: Analysis of ³H Concentration versus Time for the Duynefontein Site



Malmesbury Group Aquifer

Groundwater derived from the primary aquifer underlying the PBMR DPP site and that from the Malmesbury Group Aquifer were of a similar quality (Saayman and Weaver 2001). The similarity in quality supports the hypothesis that the two aquifer systems are to a degree hydraulically connected.

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 *c*.0.3 mg/L in groundwater in the primary aquifer) (Saayman and Weaver, 2001). Based on field measurements, EC levels in groundwater at the six boreholes range between 200 and 275 mS/m.

Four exploration boreholes were drilled at the planned Koeberg 165 MW Unit 3 location and baseline groundwater quality data has been obtained (Levin, 2001). Tritium data indicated that groundwater in the Malmesbury Group Aquifer is not recharged locally, as postulated in an earlier section of this assessment. Future pumping and dewatering may disturb this stratification and inflow of saline groundwater into the upper primary aquifer may occur.

2.1.12 Existing Groundwater Contamination

Based on site work carried out for the groundwater assessment and the subsequent monitoring programme (which is still ongoiing), there appears to be no existing contamination in the EIA Corridor Area. However, the existing KNPS is a potential source of contamination in the immediate vicinity of the site. The site is located in a nature conservaton area, the Koeberg Nature Reserve. The quality of groundwater at the majority of the site represents ambient conditions.

The KNPS has been in operation for some 30 years and there are three operational wellfields and a major unconfined aquifer in relatively close proximity. Two of these wellfields form part of the CoCT's domestic water supply network to the Greater Cape Town Area. However, there is no evidence that emissions from the KNPS have had any measurable effect on these features. Local groundwater close to the reactors shows somewhat elevated tritium levels compared to background but well below being anywhere near levels of concern for health impacts. There have been no radical and long term impacts on groundwater from the KNPS.

2.1.13 Potential Contamination Pathways

Local pathways for the migration of potential contaminants include the upper intergranular aquifer (primary aquifer) and the lower fractured rock aquifer (Malmesbury Group Aquifer). Contamination releases may migrate down-gradient through these aquifer systems. The extent of contamination would likely be restricted to within the site footprint and coastal springs / seeps which may support sensitive ecosystems that could be impacted.

Leaks of any liquid radioactive effluent will not directly affect existing groundwater users, but air emissions from the site could be transported inland by prevailing winds (regional pathway) and contaminate groundwater by incorporation into rainfall recharge. This aspect is dealt with briefly in the numerical modelling section but is a highly unlikely scenario.

2.1.14 Groundwater Use

Regional Groundwater Abstraction

The town of Atlantis has been largely dependent on groundwater for its water supply since 1976. Water distribution is controlled by the Atlantis Water Resource Management Scheme (AWRMS). The scheme utilises the Atlantis Aquifer, stormwater and recycled wastewater originating from the town. Groundwater is abstracted from the aquifer at 40 boreholes in the Witzand and Silwerstroom Wellfields, softened at a waste treatment plant and then distributed for domestic and industrial use (Flanagan and Parsons, 2005). Two basins situated in the dunes to the south-west of Atlantis serve as final retention ponds and provide for the artificial recharge of the aquifer some 500 m up-gradient of the Witzand Wellfield (Wright and Parsons, 1994).

Intermediate quality stormwater and treated domestic wastewater is discharged into Basin 7 (southern recharge basin), situated 4 km north-east of the site (**Figure 2.14**). High quality stormwater is diverted into Basin 12 (northern recharge basin). This artificial recharge counters the encroachment of naturally poorer quality groundwater (Tredoux *et al.,* 1999). Poorer quality wastewater including treated industrial effluent is discharged into the coastal infiltration basins along the coastline, 3 km north of the site. This poorer quality water cannot be used for recharge into the aquifer and it does not meet the requirements of the DWAF general standard for discharge into the Donkergat River and is, therefore, disposed of as close to the coast as possible (Wright and Parsons, 1994). 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 up-gradient at the Witzand Wellfield (Wright and Parsons 1994 and Tredoux *et al.,* 1999). The coastal recharge basins are fulfilling their function of building a positive hydraulic head along the coastline (Hobbs, 2005). The implementation of the AWRMS has provided Atlantis with the maximum benefit from its natural resources.

Groundwater demand from the Witzand and Silwerstroom wellfields was 0.43 Mm^3/a in 1977 (Dyke, 1992), 8.5 Mm^3/a in 1998/1999 (Parsons, 1999) and 3.2 Mm^3/a in 2005 solely from the Witzand Wellfield. Based on modelling results, the sustainable 'fresh water' yield of the Witzand Wellfield is 5.8 Mm^3/a (Fleisher and Eskes, 1992).

Based on data received from the CoCT 2.6 Mm^3/a of groundwater was abstracted from the two wellfields in 2007, significantly less than what was estimated during 1998 / 1999. The reduced yields and the overall significantly reduced abstraction productivity of the two wellfields is a result of iron-related clogging. The CoCT is currently considering when to start rehabilitating the boreholes to remove the precipitated iron and clear the slotted casing to increase the borehole yields back to their initially determined sustainable yields. The improved management and operation of the Atlantis Aquifer will reduce the reliance placed on the Voëlvlei Dam (Killick and Anderson 2007). There are no visible signs of any negative impacts caused by groundwater abstraction from the Atlantis Aquifer, and the Silwerstroom spring is still flowing in spite of continued groundwater abstraction from the Silwerstroom Wellfield (Parsons, 1999). The discharge rate of the Silwerstroom spring was estimated to be 0.5 Mm^3/a during 1992 (Fleisher and Eskes 1992). The Atlantis Aquifer is fully allocated and no further development or increased abstraction (other than rehabilitating the existing boreholes) will be allowed (Van der Berg *et al.,* 2007).

A number of hydrocensuses have been conducted in the vicinity of the site; during September 1999, August 2004, November 2004, and September 2007 (Parsons and

Flanagan, 2006; Levin, 2000; Flanagan and Parsons, 2005 and Bugan and Parsons, 2007). Where possible, the position (GPS), depth, groundwater level, use, and yield were obtained, and a groundwater sample collected for chemical analysis. The January 2008 hydrocensus for this assessment was carried out in areas where little or no data were available.

Groundwater is also used in the vicinity of the site as a source of water for smallholdings, brickmaking and sand mining. 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 during 2002, but municipal water is only used to a limited extent due to the relatively high cost. Groundwater is still the preferred choice for water supply (Parsons and Flanagan, 2006).

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) (SAICE, 1995). The estimated breakdown of domestic water usage indicates that 35 per cent of water is used for garden irrigation (SAICE 1995). Therefore, an average of some 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 *c*.173 000 m^3/a of groundwater being abstracted from the area south of the existing KNPS. Based on data collected during the January 2008 hydrocensus, some 30 000 m^3/a of groundwater is abstracted from four boreholes along the Aquarius Wellfield (GCS1, GCS7, GCS9 and GCS10). The groundwater from these boreholes is currently used for stock watering and irrigation purposes, as well as to supply the dam at the conservation offices at the existing KNPS. These boreholes were initially drilled to supply water to the 900 PWR MW Units 1 and 2. However, as the groundwater is relatively high in salinity, the use of these boreholes was temporarily abandoned as desalination by reverse osmosis was not cost-effective (Eskom, 2006a). It was previously estimated that 0.5 Mm^3/a of groundwater was abstracted from the Aquarius Wellfield (Parsons, 1999). The four boreholes were re-commissioned at the beginning of 2007.

Five monitoring boreholes are situated around the reactors at the KNPS (TW1 to TW5). These boreholes are presently solely used for groundwater monitoring purposes (Hön *et al.*, 2007 and Hön and Engelbrecht, 2007). A further six monitoring boreholes have also been recently drilled at the PBMR DPP site (PBMR1 to PBMR6) to monitor groundwater levels, macro chemistry and ^3H concentrations in both the primary aquifer and underlying Malmesbury Group Aquifer (Flanagan, 2008b). This monitoring programme commenced during February 2008 (Flanagan and Burgers, 2008), and was stopped in March 2010 when the PBMR project was terminated. The SSR monitoring programme was subsequently (from March 2010) expanded to include an additional 15 monitoring boreholes, which include an old Department of Water Affairs borehole and four of the PBMR boreholes. Also included are three piezometers installed in some of the wetlands on site. This brings the total number of groundwater monitoring points to 17 boreholes and three piezometers. See **Figure 2.2** for the localities of these monitoring points.

On-site Groundwater Abstraction

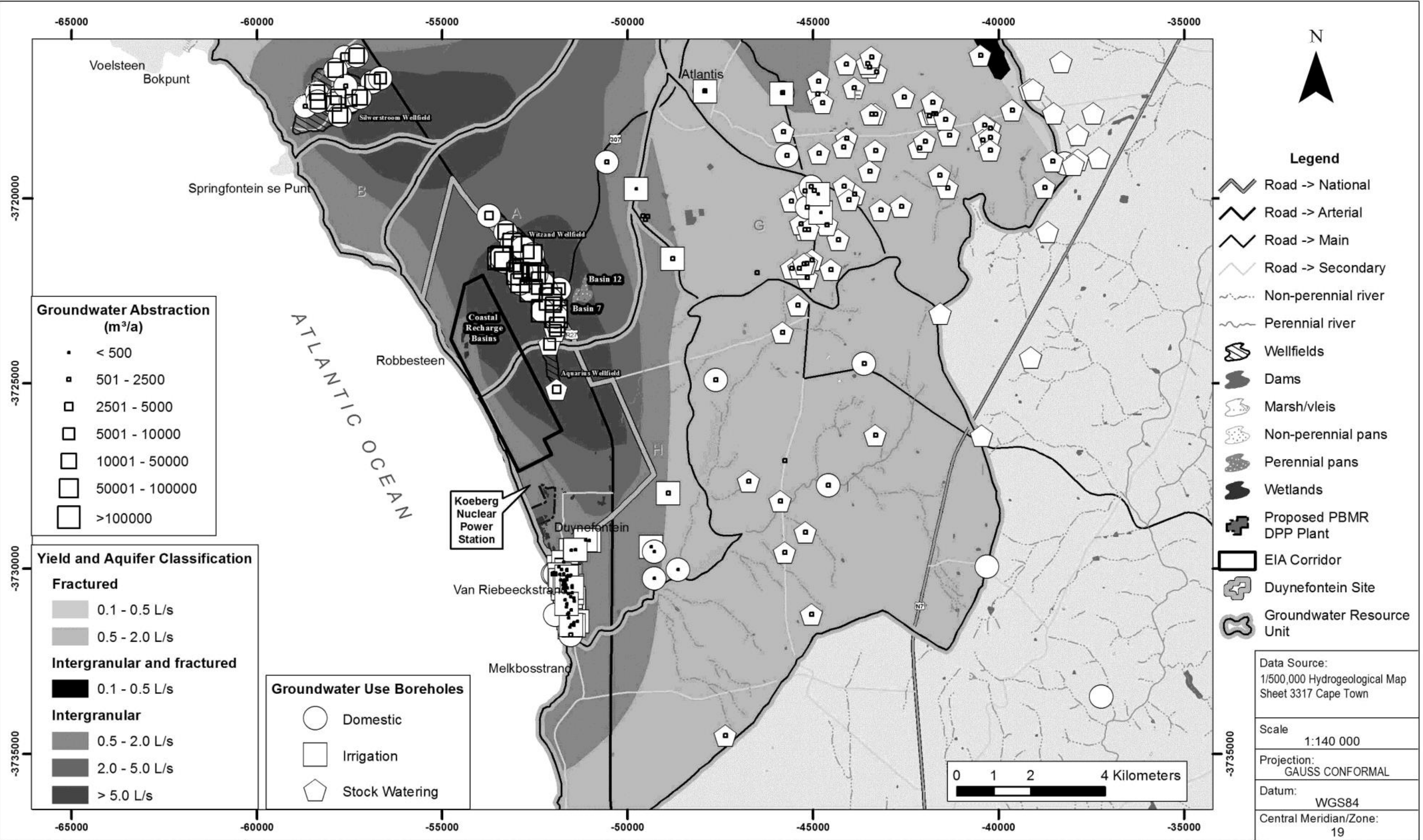
Groundwater is presently not used at the site. The nearest abstraction points are from boreholes at the Aquarius and Witzand Wellfields. The six boreholes drilled on-site into the Malmesbury Group Aquifer during the work for this assessment yielded between 2 and 12 L/s. The Malmesbury Group Aquifer is presently not utilised in the area and this resource is therefore exploitable, and is a potential source of water for the proposed site.

Ecosystem Water Use and Interaction with Surface Water

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 south of the site. The slack areas between a series of low lying east-west oriented dunes give rise to a mosaic system of alkaline dune-slack wetlands (Day, 2007a). No other natural freshwater systems or springs are known to occur at the site. Wetland areas are shown on all the Duynefontein site Figures.

These dune wetlands are fed primarily by the seasonal fluctuations in the water table, forming pools of shallow, brackish water during winter. These wetlands are dry in summer when the water table drops. These pools provide a breeding habitat for frogs as well as numerous aquatic and semi-aquatic invertebrates including crustacean fauna that occur in seasonal wetland habitats. Wet season salinities in the wetlands are probably elevated, as a result of marine influences such as sea mists and off-shore winds. The wetlands are considered of high local and regional importance, although their similarity to other wetlands north of the site has not yet been established (Day, 2007a).

A series of coastal infiltration basins has been excavated between the dunes and may be linked to an increase in seepage and deterioration of the limestone cliffs along a section of nearby coastal shoreline (Day, 2007a and Day, 2007b). The coastal infiltration basins are highly artificial habitats, comprising deep, permanent, open water bodies, vegetated by species that thrive under conditions of nutrient enrichment (Day, 2007a and Day, 2007b). The coastal infiltration basins provide permanent habitat to a variety of swimming waterfowl, but are of limited value to wading birds. Fish have been introduced to the ponds, primarily to provide an early warning of water quality problems. The coastal infiltration basins are unnatural water features of low quality, but locally rare, permanent freshwater habitat, artificially contributing to plant and animal diversity in the



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Projection:	GAUSS CONFORMAL
Datum:	WGS84
Central Meridian/Zone:	19

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SPECIALIST STUDY: GEOHYDROLOGY
GROUNDWATER USE AT AND SURROUNDING THE DUYNEFONTEIN SITE

Date:	Compiled by:
31 10 2012	GOES/FUBM
Project No.	Fig No.
378677	2.14

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Revision: C Date: 11 11 2014

area. They play an important role in terms of providing a hydraulic barrier for the protection of the Atlantis Aquifer from seawater intrusion (Day, 2007a).

Several short, perennial streams flow directly towards the Atlantic Ocean in the vicinity of the site. Most of these streams disappear into the flat areas near the coast or cannot maintain open river channels across the coastal dunes (Mawatsan,2006). No 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 (Day, 2007a).

2.1.15 Aquifer Classification and Vulnerability

Atlantis Aquifer

The Atlantis Aquifer is classified as a Sole Source aquifer system (Parsons 1995 and Parsons and Conrad, 1998). Although smallholdings in the vicinity of the site are dependent on groundwater, a reticulated pipeline was constructed during 2002. The primary aquifer system towards the east of the site is therefore classified as a Major Aquifer system vulnerable to anthropogenic impacts (Parsons and Flanagan, 2006). Its vulnerability is mainly due to its shallow unconfined water table and high permeability.

Malmesbury Group Aquifer

The Malmesbury Group Aquifer at the site has previously been classified as a Minor Aquifer system, as this aquifer usually has low borehole yields, produces groundwater of variable quality and is of limited significance (Parsons, 1995 and Parsons and Conrad, 1998). Minor aquifers have a moderate to low vulnerability to anthropogenic impacts.

Based on the drilling results, where blow yields in excess of 6 L/s were encountered, the Minor Aquifer classification may be in question. Previous difficulties encountered in locating water-bearing structures in the Malmesbury Group resulted in water supply programmes concentrating mainly on the overlying primary aquifer (Dyke, 1992). However, it should be borne in mind that the aquifer classification quoted is based on regional characteristics, not site-specific ones.

2.1.16 Conceptual Model

The conceptual model for the site (
Figure 2.16) is based on detailed information and data derived from this study and extensive previous studies. Key features are:

- The topography is relatively flat with a gentle slope towards the coast;
- No river channels drain the immediate site;
- The site overlies two aquifer systems, namely the southern extent of the upper-lying primary or intergranular Atlantis Aquifer and the deeper-lying weathered and fractured-rock (secondary) aquifer system of the Malmesbury Group;
- These two aquifer systems are generally separated by a weathered (clay) zone in the bedrock, which constitutes an aquitard;
- The thickness of the primary aquifer at the site is between 17 and 25 m, the rest groundwater level is 2 to 5 m below ground level (mbgl) and the overall thickness of the sediments is 14 to 27 m;
- The site is located very close to the coastline and therefore in terms of the hydrological / groundwater cycle, is located in a groundwater discharge zone. Groundwater at the site is thus near the end of its flow path;

- The interpreted direction of groundwater flow is in a south-westerly direction towards the coast.

In addition, the following specific characteristics and geohydrological conditions apply (based on existing data and information):

- The hydraulic gradient across the site is in the order of 0.01. Groundwater therefore flows under a relatively low gradient towards the coastline;
- Groundwater was calculated to flow towards the coast at a rate of *c.*2.6 m/d, which indicates a relatively quick migration across the site;
- Due to the unconfined nature of the upper sediments, recharge takes place over the entire area. A recharge estimate of 15 per cent is considered to be reasonable;
- Borehole yields in the range of 0.5 to 5 L/s are common in the primary aquifer sands underlying the site;
- High yields ranging up to 12 L/s were encountered in the Malmesbury Group Aquifer, with the mean yield being 6 L/s;
- Based on these preliminary results, the Malmesbury Group Aquifer is a potential additional source for groundwater supply;
- The secondary aquifer is a semi-confined system which is in hydraulic connection with the overlying primary aquifer.

2.1.17 Numerical Modelling

a) REGIONAL MODEL

The regional model covered the whole of quaternary catchment G21B (**Figure 2.15**). The network constructed for the area consists of 119 x 345 cells in the x and y directions, respectively. Each of the cells is 100 x 100 m. The coordinates for the modelled area are:

- Lower left corner: -59 600, -3 744 500;
- Upper right corner: -39 700, -3 710 000.

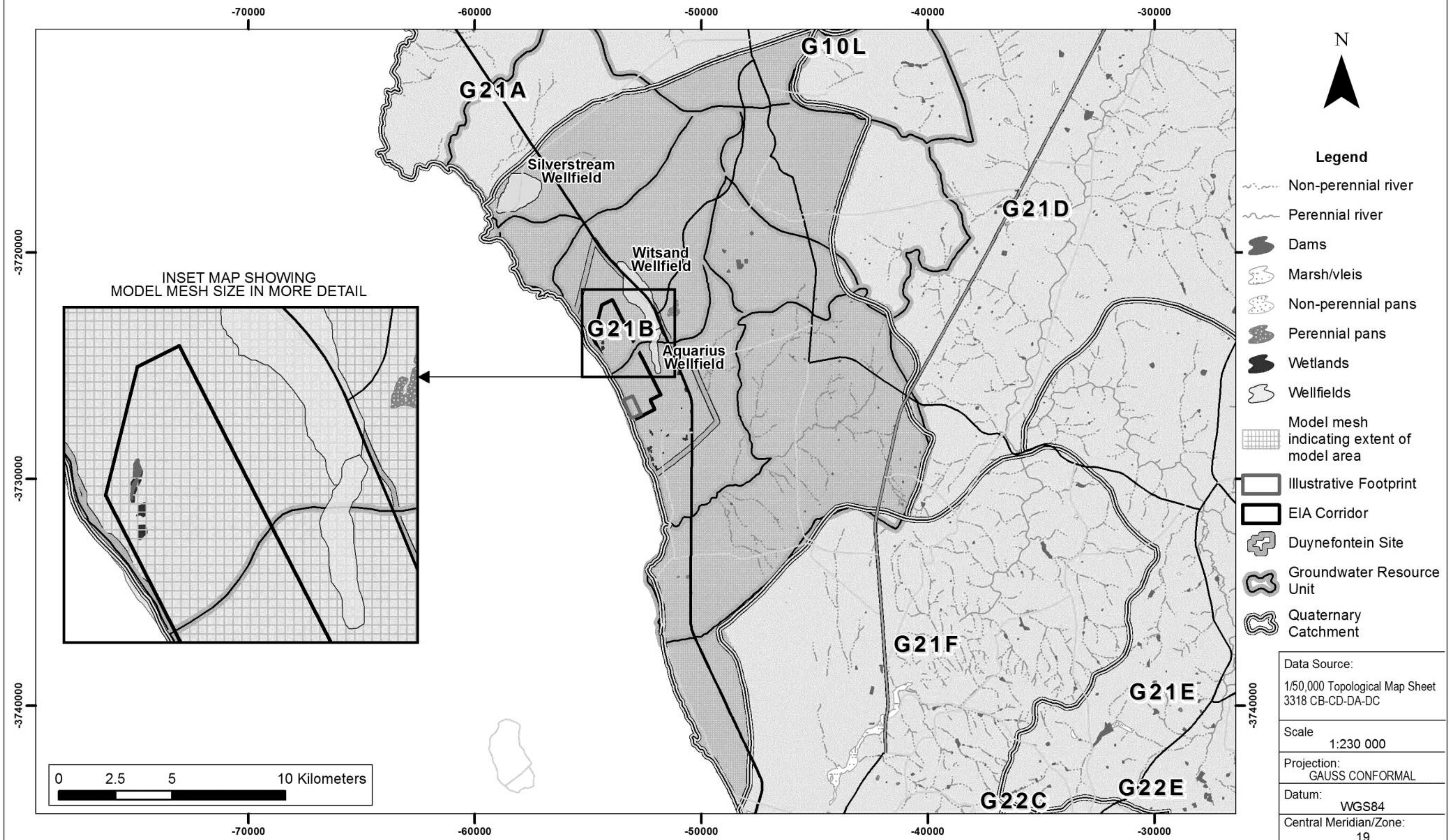
The model network extends over an area larger than the area under investigation to ensure that the model boundaries will not affect simulated results.

<u>Modelling Software and Solver</u> - *MODFLOW88/96* (Harbaugh and McDonald, 1996) a modular three-dimensional finite difference groundwater flow model which was developed by the U.S. Geological Survey, was the software used during this investigation. It is an internationally accepted and benchmarked modelling package that calculates the solution of the groundwater flow equation using the finite difference approach. The Preconditioned Conjugate-Gradient Solver Package (*PCG2*) is used to solve the finite difference equations in each step of the *MODFLOW* stress periods.

<u>Boundary conditions</u> - The Atlantic Ocean was set as a constant head of 0 mamsl. The Sout River was also set as a constant head. All other boundaries were set as no flow boundaries.

<u>Initial conditions</u> - In order to set up a groundwater flow model for the area, a water level contour map was generated, as previously discussed.

<u>Sources and sinks</u> - Sources and sinks are defined as recharge and abstraction sources in the aquifer, respectively. Sources can be precipitation and inflow from surface water and recharging boreholes. Sinks can be abstraction boreholes, mines, springs, evapo-transpiration and outflow to surface water. The initial groundwater recharge value used in the model was 15 per cent of mean annual precipitation.



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EXTENT OF REGIONAL MODEL AREA: DUYNEFONTEIN SITE

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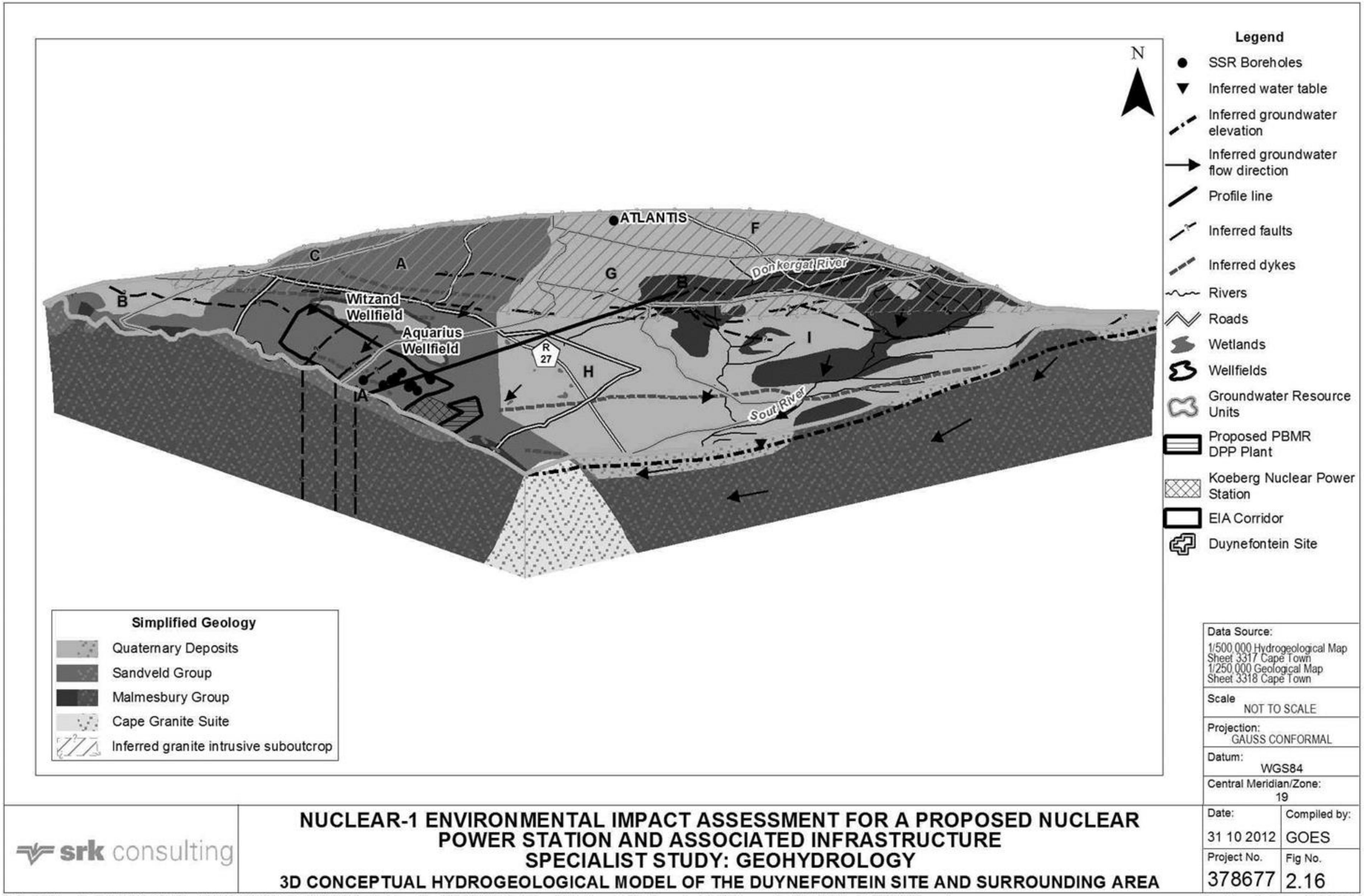

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Aquifer parameters - The transmissivity values obtained from pumping tests conducted during the geohydrological investigation for this assessment are listed in **Table 2.7**. The specific yield of this system is assumed to be 0.15 and the calculated storativity values are documented in **Table 2.7**. Also included in this table are the assumed porosity values.

Table 2.7: Hydraulic Parameters for Boreholes Drilled at the Duynefontein Site

Borehole	Transmissivity (m^2/d)	Storativity	Hydraulic Conductivity (m/d)	Porosity (%)
Primary Aquifer Parameters				
SRK-KG2	22	2×10^{-1}	0.88	20
SRK-KG5	140	3×10^{-1}	5.60	20
SRK-KG8	57	1.1×10^{-1}	2.71	20
SRK-KG10	16	2.5×10^{-1}	0.94	20
Bedrock Aquifer Parameters				
SRK-KG1	19	1.4×10^{-4}	0.3	0.5
SRK-KG3	5	8.6×10^{-4}	0.1	0.5
SRK-KG4	70	1.4×10^{-3}	1.7	0.5
SRK-KG6	31	1.9×10^{-3}	0.8	0.5
SRK-KG7	113	2.8×10^{-4}	3.0	0.5
SRK-KG9	180	2.9×10^{-3}	6.0	0.5

Transmissivity in a fractured aquifer such as the Malmesbury Group Aquifer varies naturally and it is not possible or necessarily desirable to get consistent values. Having T values varying between 5 and 180 m^2/day is therefore a function of aquifer anisotropy and heterogeneity, not any flaw in investigative or analytical methods.

Numerical flow model - A steady state groundwater flow model for the study area was constructed to simulate undisturbed groundwater flow conditions. These conditions serve as starting heads for the transient simulations of groundwater flow where effects such as dewatering are simulated.

Steady state calibration – The model was calibrated by changing the T and recharge parameters to within realistic values. One hundred and ninety six boreholes were used to calibrate the steady state groundwater flow model. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads (see **Figure 2.17** and **Figure 2.18**). A square of the Pearson product moment correlation coefficient of 0.84 was achieved, which was viewed as acceptable, taking into account the variability of aquifer conditions and number of boreholes included in the calibration. As can be seen in Figure 2.17, the model residuals (difference between observed and modelled water levels) is <5 m for nearly all boreholes close to the site.

The model mass water balance is shown in Table 2.9. As can be seen, the mass balance percent error is *c*.0.0029 per cent, which is within the calibration criteria requirement of <0.5 per cent.

Table 2.8: Duynefontein Regional Steady State Mass Water Balance

	Inflow (m^3/d)	**Outflow (m^3/d)**
Recharge	31 630	0
Sea (Constant Head)	1 213	56 016
Atlantis Recharge Ponds	2 000	0
Rivers	35 149	13 974
Pumping Boreholes	0	0
TOTAL	**69 992**	**69 990**
Mass Balance Percent Error	**0.0029%**	

The model calibrated best with a T of 75 m^2/d, while T of the geological lineaments was set at 200 m^2/d. The model calibrated best with an average recharge for the area of 10 per cent, with a recharge of 25 per cent for non-vegetated dunes.

It is important to note that as this is a regional model, a geometric mean value for the transmissivities was determined and set for the entire area. Blow yield data and yield data recorded during the hydrocensus were included in this analysis.

In the local model, the above-mentioned values can differ and also differ from some of the test pumping derived T values. However, the modelling is considered to provide a better indication of more regionally applicable T values for predictive purposes. A number of scenarios were then modelled and are discussed below. Flow in individual fractures is not covered by this modelling.

A sensitivity analysis was done and T was found to be the most important parameter. The values used for recharge and porosity are all within ranges of the numerous previous studies carried out by other independent researchers in the area. The Atlantis Aquifer is one of the most researched aquifers in South Africa and there are numerous reports and theses documenting the aquifer parameters.

Figure 2.17: Simulated versus Observed Data Sets for the Duynefontein Model

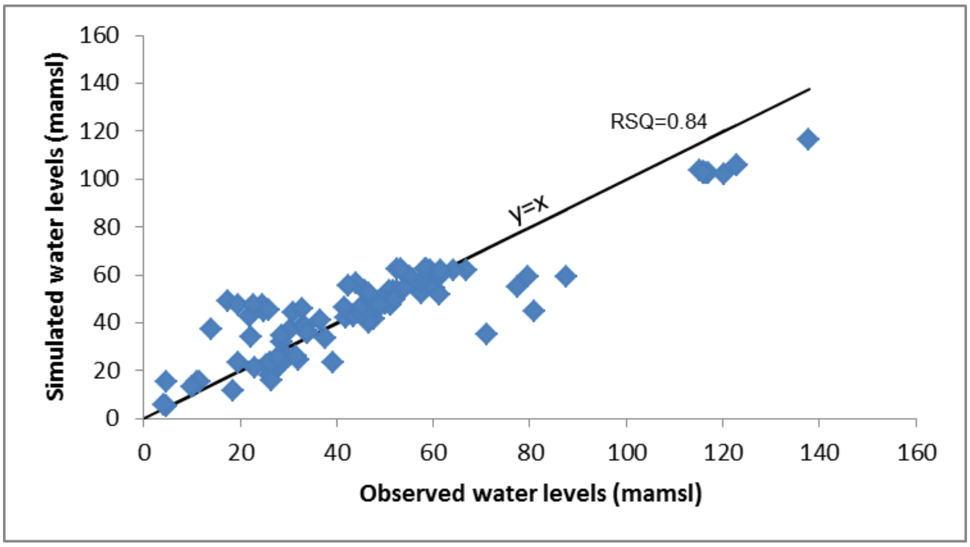


Figure 2.18: Simulated versus Observed Water Levels for the Duynefontein Model

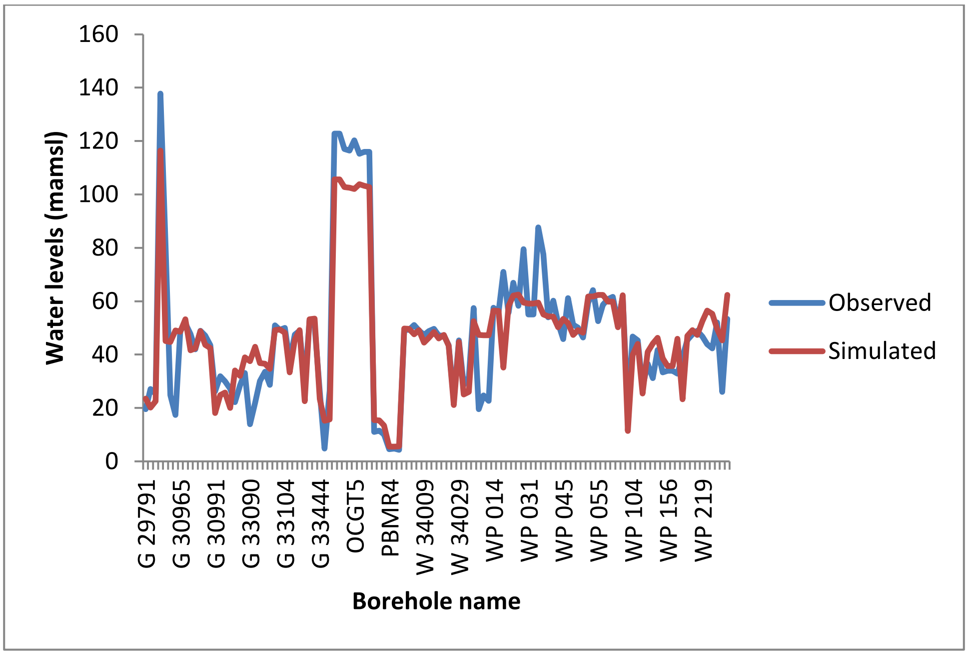
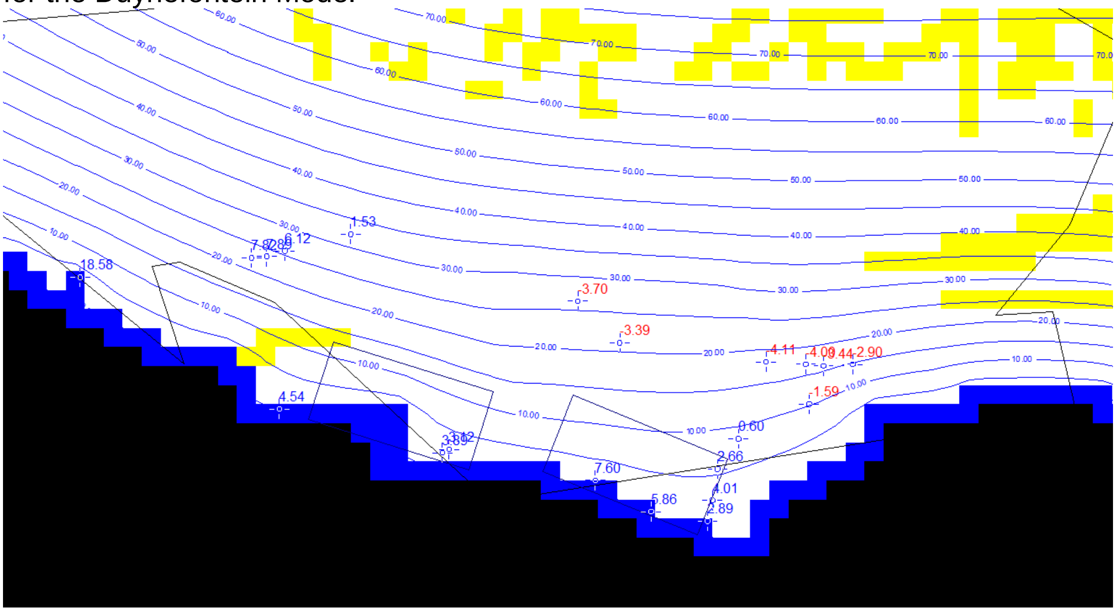


Figure 2.19: Residuals (Observed minus Simulated Water Levels) and Head Contours for the Duynefontein Model



<u>**Scenario using regional model: Potential groundwater contamination due to air pollution from site**</u> **–**

Scenario 1: Deposition of tritium

The nature of the subsurface (vegetation and soil types present) influence the movement of ^{3}H and therefore this scenario only serves as an indication of what can occur, thus being qualitative, not quantitative. Using average annual emissions of EPR and AP1000 units to make up the 4 000 MWe indicates that most of the wetlands and boreholes would be affected by emissions. However, the concentrations will be low, i.e. *c*.10 TU. This is for a 20-year simulation period. This is equivalent to 1.18 Becquerels per litre (Bq/L); The WHO's limit for drinking water is 10 000 Bq/L. Observations/monitoring during operation of the KNPS have shown that actual impacts of normal operational gaseous releases are far less than the modelled values. This is probably an indication of greater attenuation by vegetation and the unsaturated zone.

b) LOCAL MODEL

For the local model (**Figure 2.22**) the western boundaries are the Atlantic Ocean (west), the groundwater unit (north and east) and the Sout River (south). A geological lineament forms the north eastern boundary. There are 238 300 cells in both the x and y directions. Each of the cells is 50 x 50 m. The coordinates for the modelled area are:

- Lower left corner: -54 000, -3 732 100;
- Upper right corner: -46 900, -3 720 200.

In order to include more detail in the mode three layers were included, which are:

- Layer 1: Intergranular primary aquifer;
- Layer 2: Combination of intergranular and weathered aquifer;
- Layer 3: Malmesbury fractured rock and weathered aquifer including geological lineaments

The local model was recalibrated in 2010 by using the wetlands and SSR monitoring data. Subsequent re-simulation of the scenarios did not show any material changes from the original results obtained.

Boundary conditions - The western boundary (Atlantic Ocean) is initially set as a constant head boundary of 0 mamsl. All other boundaries were set as no flow boundaries, except for the Sout River which was also set as a constant head.

Initial conditions - The initial water levels were once again used as initial conditions in this model.

Sources and sinks - The initial groundwater recharge values used are previously documented.

Aquifer parameters - The initial aquifer parameters used in the model are listed in **Table 2.9**.

Table 2.9: Aquifer Parameters for the Duynefontein Site

Layers	Transmissivity (m^2/d)	Storativity	Vertical Hydraulic Conductivity (m/d)
Layer 1	75	2×10^{-1}	2.4
Layer 2	10	1×10^{-3}	4×10^{-4}
Layer 3	50	1×10^{-3}	0.2

Calibration of the steady state flow model - The results of the steady state simulation are shown in
Figure 2.20 and **Figure 2.21**. In order for the model to calibrate the transmissivity of layer 1 was set at 75 m^2/d along the coast and 120 m^2/d for the rest of the layer, except in the north-eastern corner, where it was set to 40 m^2/d. The calibrated recharge for the area was set at 10 per cent, with a recharge of 25 per cent set for non-vegetated dunes. Layer 3 was assigned a transmissivity of 40 m^2/d. The calibration results are good considering the complexity of the aquifer system.

Figure 2.20: Simulated versus Observed Data for the Duynefontein Site

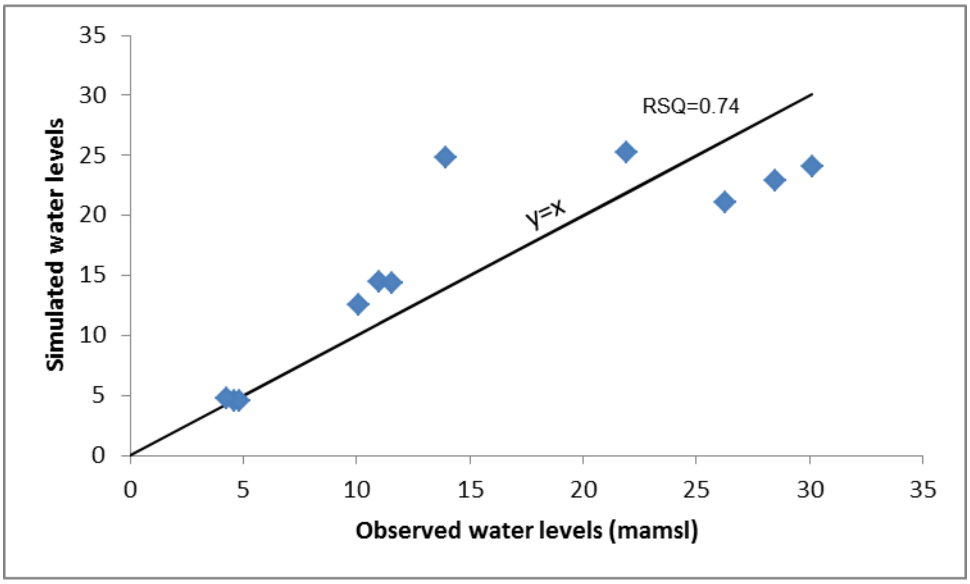
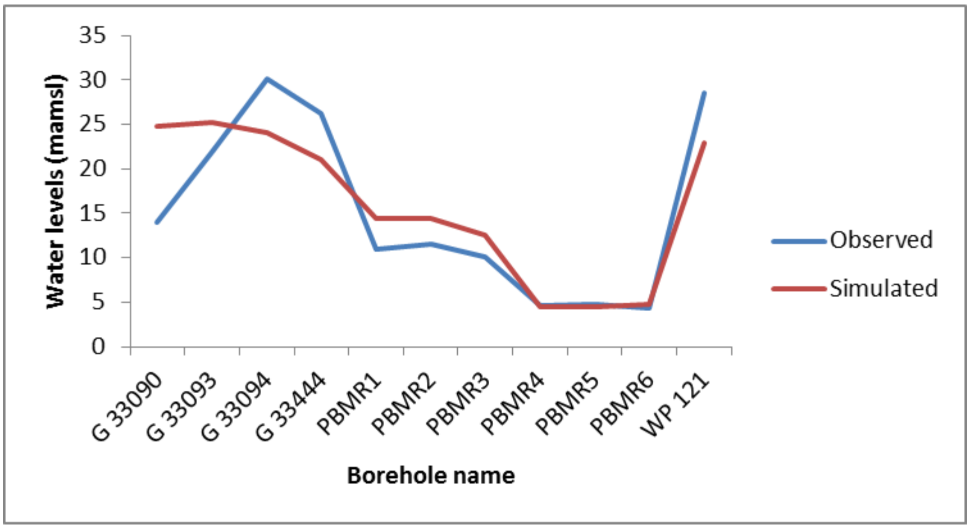


Figure 2.21: Simulated versus Observed Water Levels for the Duynefontein Site



Numerical mass transport model - The numerical mass transport model was set up with the same parameters as for the regional model.

Scenarios using local model - Once the model was calibrated predictive scenarios were run to assess the impacts of various on-site activities on the groundwater system. These activities include dewatering and the movement of potential contamination.

Scenario 1: Dewatering a hypothetical "footprint"

This scenario models dewatering of an entire hypothetical footprint of approximately 150 ha (highly unlikely scenario) to simulate excavation of the foundations for a NPS. The zone of depression, extending approximately 6 km inland (0.1 m drawdown contour), is shown in
Figure 2.23. The expected inflows with depth are shown in **Table 2.10**. In this scenario the maximum drop in groundwater levels in the vicinity of the wetlands shown in

Figure 2.23 is <1 m. These wetlands are observed to naturally dry up during the dry summer months. This scenario is a worst case one and is unlikely to take place.

Table 2.10: Scenario 1 Expected Inflows at the Duynefontein Site

Depth (mbgl)	Inflow (m^3/d)
10	4 200
20	5 200

Scenario 2: Dewatering a third of the footprint

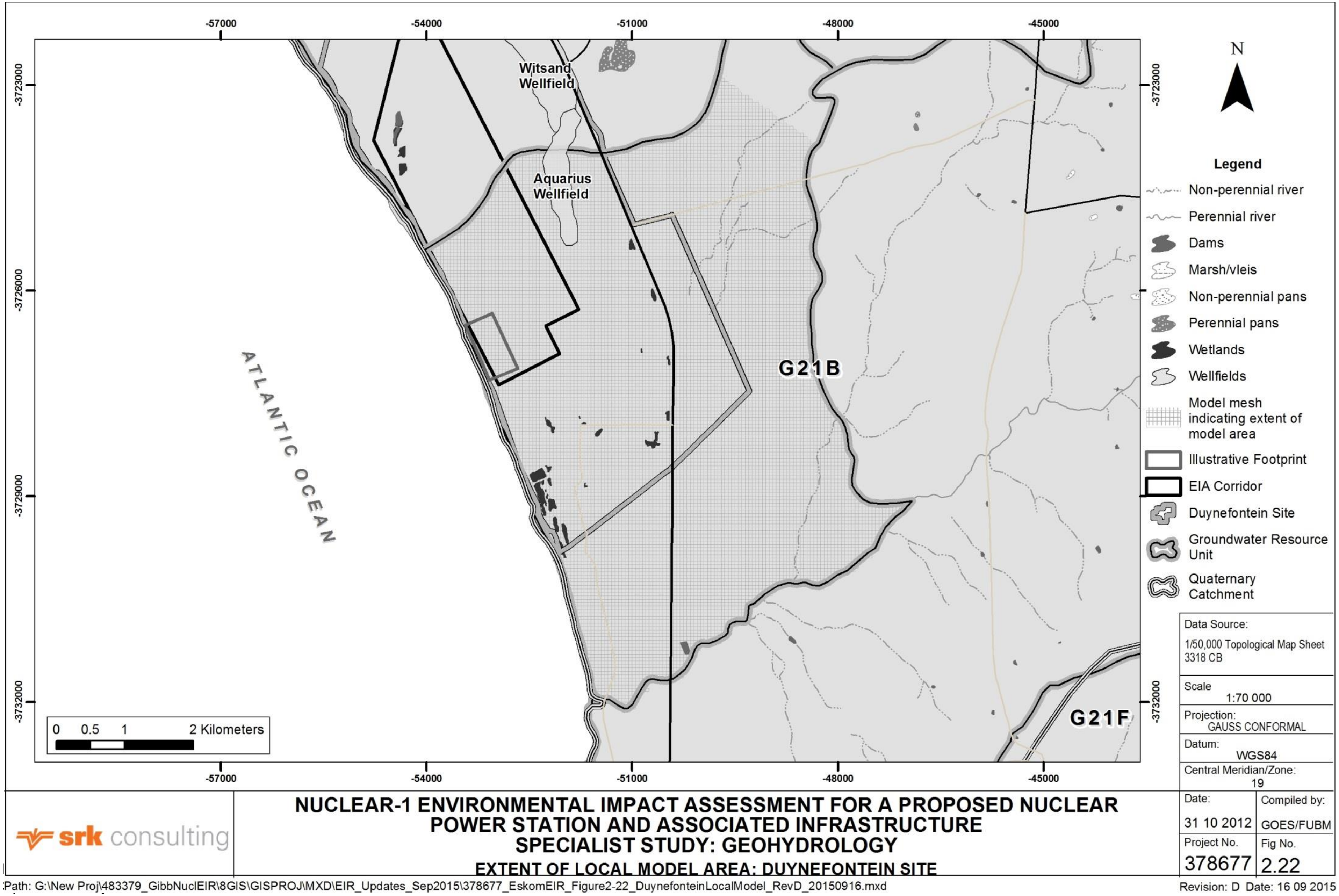
In this scenario the northern third of a footprint is dewatered to represent the installation of a single Nuclear-1 type NPS. The zone of depression extending approximately 1.5 km inland (0.1 m drawdown contour) is shown in **Figure 2.24** and the expected inflows with depth are shown in **Table 2.11**. Dewatering of one third of the footprint (likely scenario) will not impact the wetlands.

Table 2.11: Scenario 2 Expected Inflows at the Duynefontein Site

Depth (mbgl)	Inflow (m^3/d)
10	3 000
20	3 500

A 95 per cent impermeable cut-off barrier was inserted in the first two layers of the model surrounding the footprint. The length of the barrier is correctly defined by the site boundary, however, the modelled width of the barrier is 50 m, as defined by the model cell size. This will not have a major impact on flow directions and modelled drawdowns, however, as the barrier will still act as a flow impeder in the same orientation. By including the cut-off barrier, the maximum inflow is reduced to 2 000 m^3/d. The zone of depression is significantly smaller (reduced to <100 m) and no wetlands are impacted, as can be seen from **Figure 2.24**. This is the most likely scenario to occur.

There will be an impact on groundwater equilibrium when dewatering/ groundwater control measures are implemented for excavation of the foundations for the NPS. These control measures could include cut-off walls and pumping boreholes/wells. They will result in local drawdown of the water table in the short-term but equilibrium will be restored outside of the NPS footprint area with time. This is what was observed during and after the construction of the KNPS (Eskom, 2006a) and is discussed further under the Mitigation Measures section. Managed artificial recharge could be employed to assist with restoring the *status quo*, with pumped groundwater being fed back into the aquifer.


-57000
-54000
-51000
-48000
-45000
-3723000
-3726000
-3729000
-3732000
N
Witsand Wellfield
Aquarius Wellfield
ATLANTIC OCEAN
G21B
G21F
0 0.5 1 2 Kilometers
Legend
Non-perennial river
Perennial river
Dams
Marsh/vleis
Non-perennial pans
Perennial pans
Wetlands
Wellfields
Model mesh indicating extent of model area
Illustrative Footprint
EIA Corridor
Duynefontein Site
Groundwater Resource Unit
Quaternary Catchment
Data Source:
1/50,000 Topological Map Sheet 3318 CB
Scale
1:70 000
Projection:
GAUSS CONFORMAL
Datum:
WGS84
Central Meridian/Zone:
19
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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
EXTENT OF LOCAL MODEL AREA: DUYNEFONTEIN SITE
Date:
31 10 2012
Compiled by:
GOES/FUBM
Project No.
378677
Fig No.
2.22
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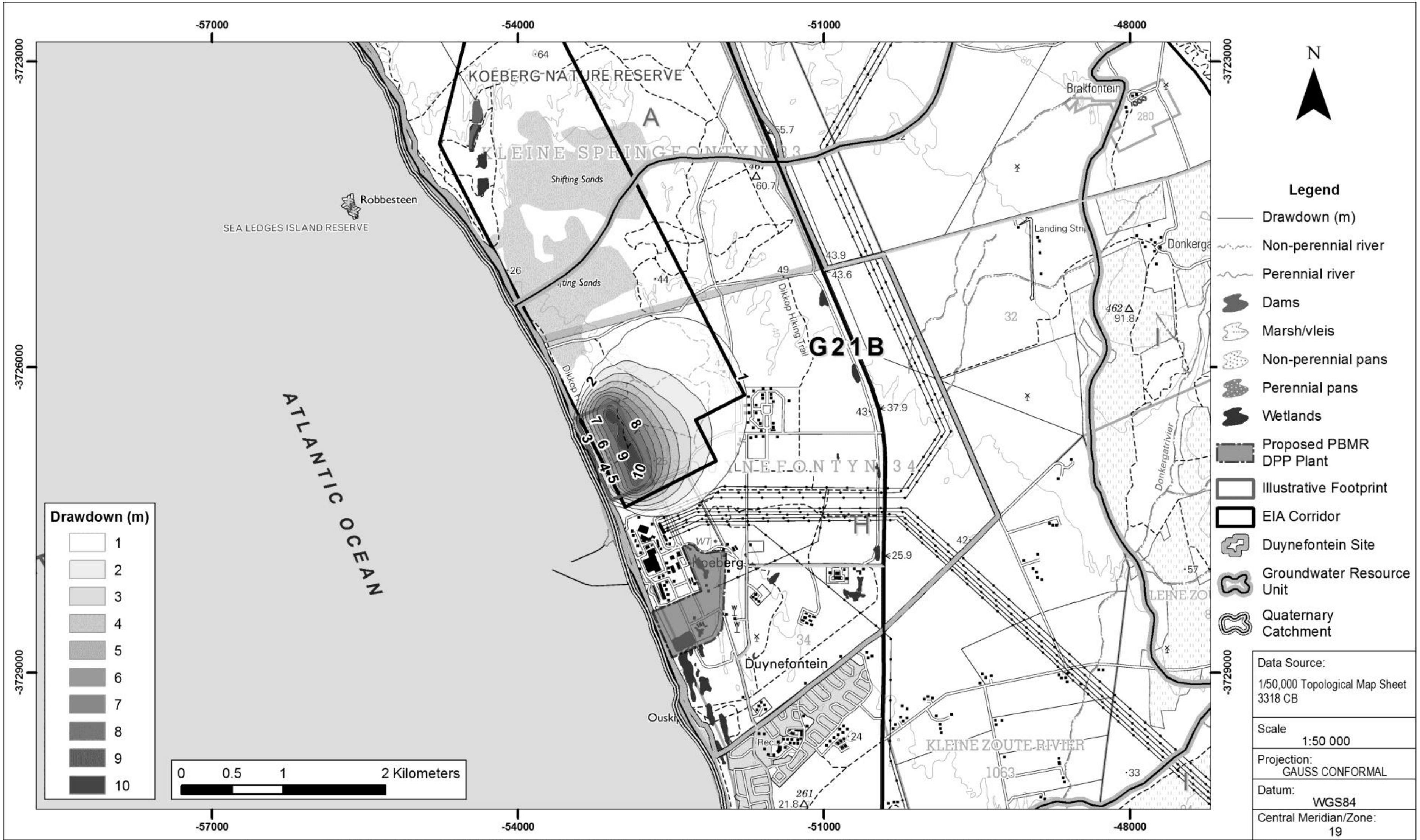
Revision: D Date: 16 09 2015



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Datum:	WGS84
Central Meridian/Zone:	19

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
ZONE OF DEPRESSION SCENARIO 1 (DRAWDOWN IN M): DEWATERING THE ENTIRE ILLUSTRATIVE FOOTPRINT, DUYNEFONTEIN SITE

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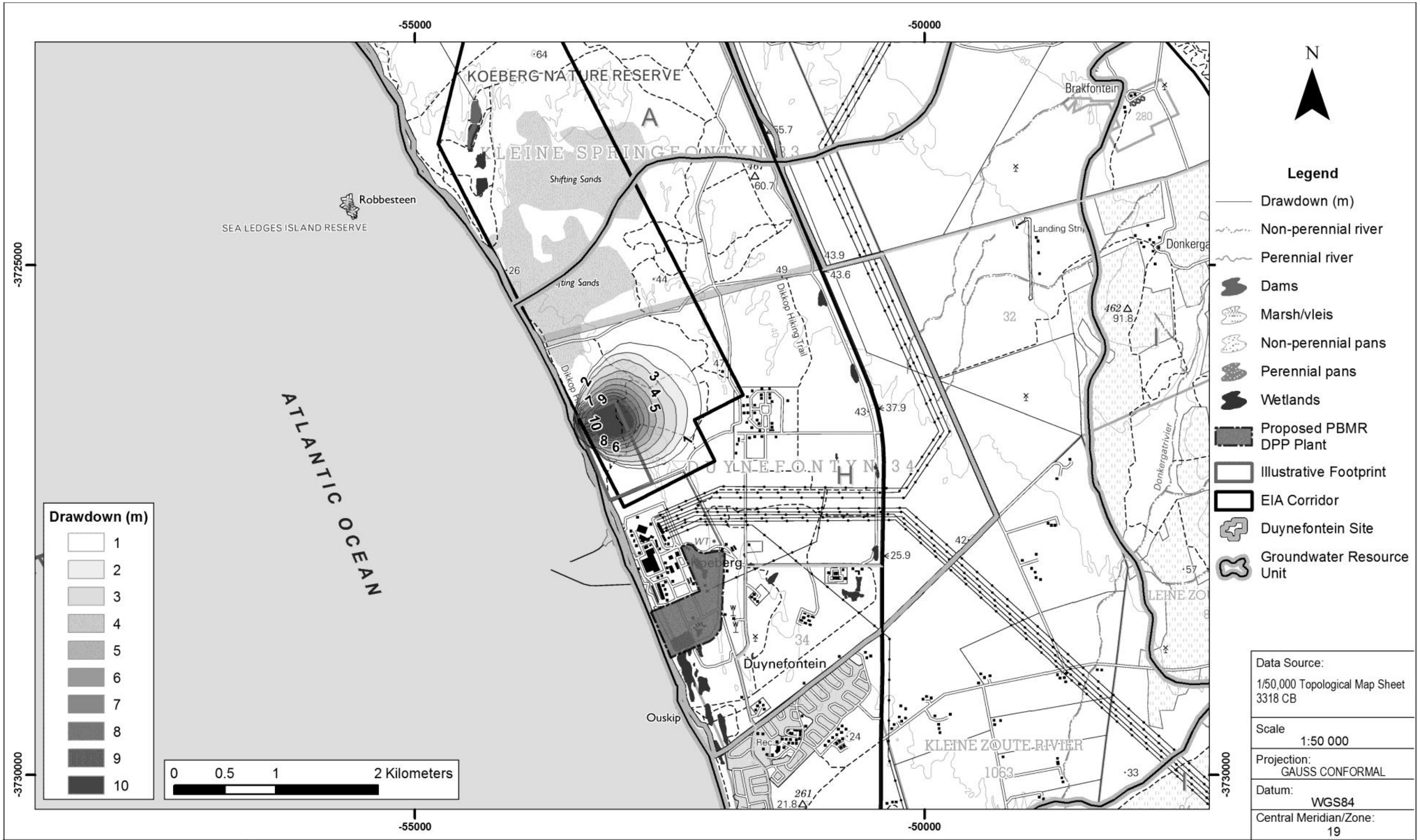

srk consulting	**NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY ZONE OF DEPRESSION SCENARIO 2 (DRAWDOWN IN M): DEWATERING A THIRD OF THE ILLUSTRATIVE FOOTPRINT, DUYNEFONTEIN SITE**	Date: 31 10 2012	Compiled by: GOES/FUBM
		Project No. 378677	Fig No. 2.24

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Revision: D Date: 16 09 2015

Scenario 3: Impact of increase in seawater level on groundwater system
The sea level is raised by *c*.1.2 m in this scenario based on predictions in the Inter-governmental Panel on climate change (*op cit*). The impact on site groundwater levels is indicated to be a maximum of *c*.0.55 m, an insignificant amount that can easily be taken account of in any groundwater control/management system. These simulations will be updated as necessary with any increases in predicted rise in sea level due to global warming and should likewise be controllable within the groundwater management system designed.

Scenario 4: Impact of increase in seawater level on dewatering
This scenario is a repeat of scenario 1, but with the sea level raised by 0.8 m. The zone of depression is shown in **Figure 2.25** and the expected inflows with depth are shown in **Table 2.12**. The maximum drop of groundwater levels in the vicinity of the wetlands shown in **Figure 2.25** will be <1 m. As with scenario 3, increases in predicted sea level rise will be taken into account but dewatering will most likely take place before a significant rise occurs if the site is approved for an NPS.

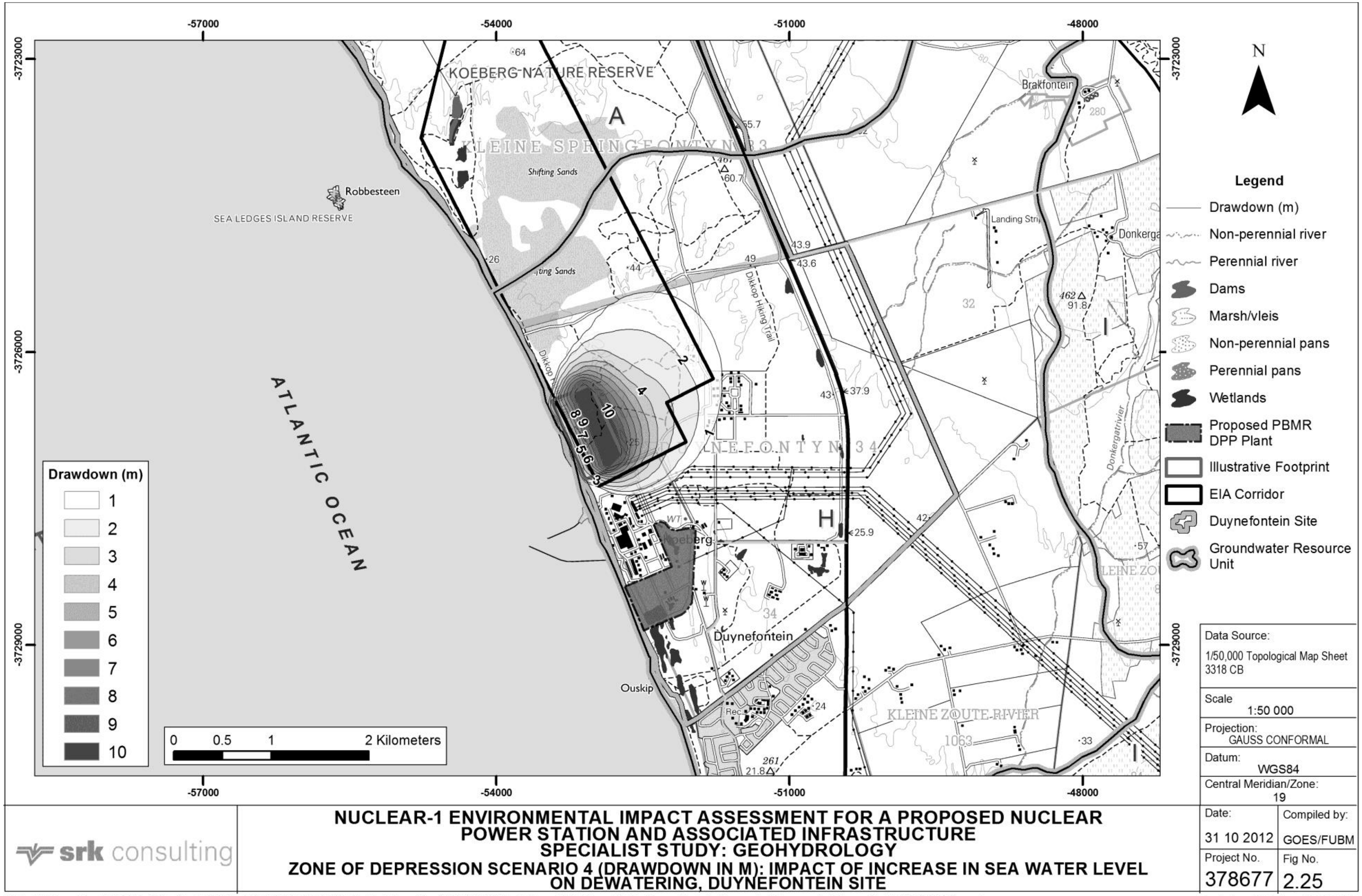
Table 2.12: Scenario 4 Expected Inflows at the Duynefontein Site

Depth (mbgl)	Inflow (m^3/d)
10	5 100
20	6 050

Scenario 5: Groundwater as a potential source of water
The impact of pumping from the Aquarius Wellfield has previously been modelled and found unlikely to affect the existing KNPS or proposed PBMR sites. Water quality from this wellfield is poor and it is unlikely that it will be used for anything more than limited pumping for game watering.

Scenario 6: Potential contamination of the site
In this highly unlikely scenario, potential contamination from the NPS is simulated with the assumption that the entire footprint is 100 per cent contaminated (contamination type is not specified for this hypothetical scenario). The contamination plume after 50 years is shown in **Figure 2.26**. The majority of the contamination migrates towards the ocean with time. However, there is a 200 m zone around the footprint that could become contaminated. This contamination plume is contained in the direct vicinity of the footprint and does not appear to have an influence on any wetlands or water supply boreholes. Contaminants entering into fractures in the Malmesbury Group Aquifer could behave differently but general flow directions and impacted areas would be similar. An exception to this could occur if there was pumping taking place from such fractures. The area potentially impacted would not be larger for radioactive contaminants. Assuming that an impermeable cut-off wall is installed around the reactor area, this will help contain liquid contaminants emanating from this source.

Scenario 7: Potential for seawater intrusion
In this scenario the potential of seawater intrusion into the site aquifers is investigated, under the influence of dewatering of the foundation of the footprint area. As *PMWIN* is not ideal for simulating seawater intrusion, it can only provide a qualitative indication of the possibility of such intrusion. *PMPATH* is included in the *PMWIN* package. This add-on package simulates the advective transport of particles within an aquifer system. Particles were introduced along the coastline and tracked with time. The results indicate that seawater intrusion could occur within a radius of 600 m along the coastline in the vicinity of each footprint with dewatering of the footprint. Only one wetland to the east appears to be affected and under this scenario it could become more saline.



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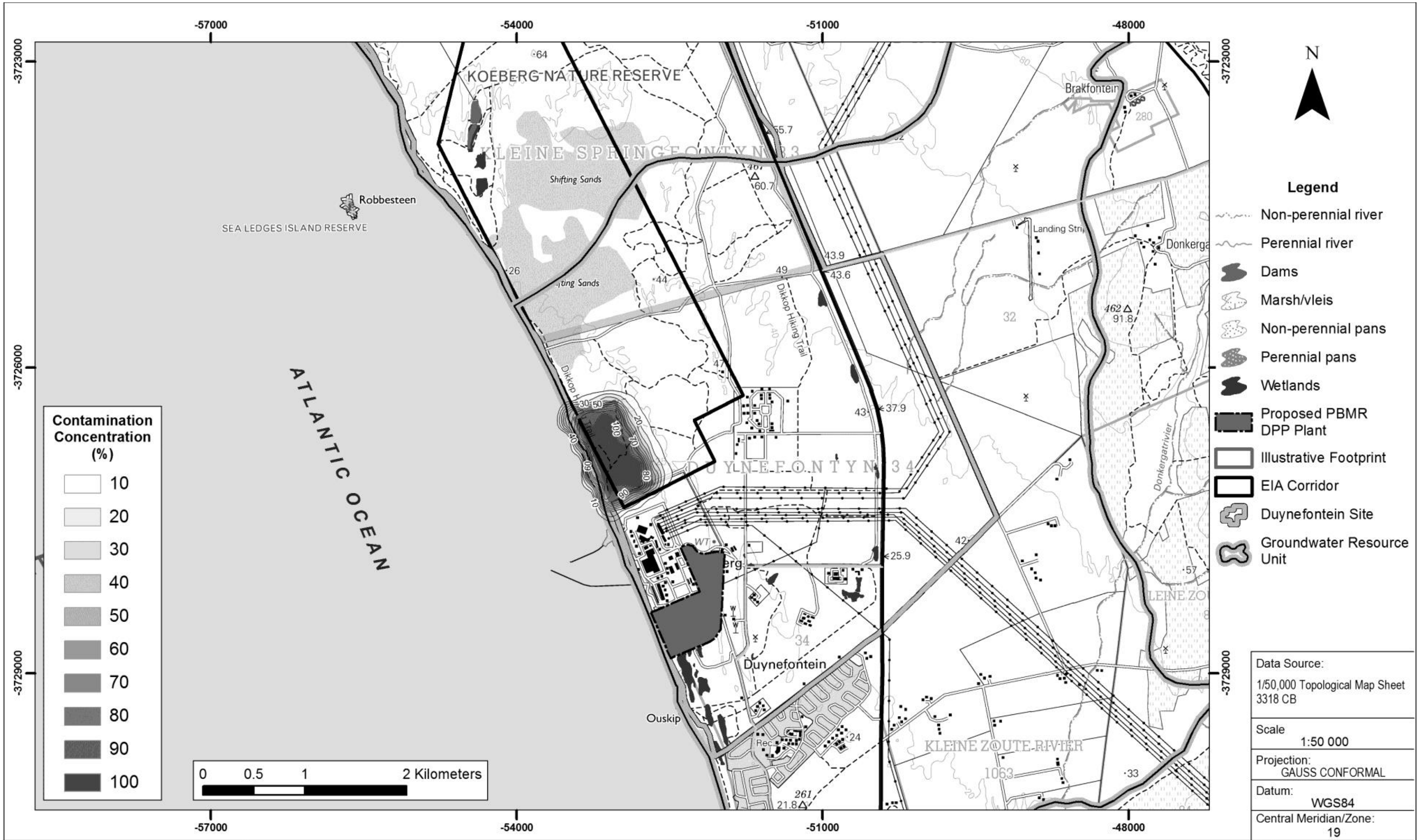

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
NUCLEAR CONTAMINATION PLUME AFTER 50 YEARS: DUYNEFONTEIN SITE

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c) CONCLUSIONS

The numerical modelling indicates that the maximum extent of the zone of depression would be a maximum of 6 km inland (0.1 m drawdown contour) with the dewatering of an entire footprint (unlikely). This zone intercepts some of the wetlands within the vicinity of the proposed footprint. With the dewatering of a third of the footprint (likely) the zone of depression would extend a maximum of the approximately 1.5 km inland (0.1 m drawdown contour). This zone will not impact the wetlands. By including a 95 per cent impermeable cut-off wall (in the first two layers of the model) surrounding the footprint, the maximum zone of depression is significantly smaller (reduced to <100 m) and no wetlands are impacted.

An increase in seawater levels will lead to an increase in groundwater levels along the coastline. However, the maximum increase in the groundwater level is expected to be only *c*.0.55 m across the entire site. This (or potentially up to 1 m or more) is not significant for the NPS foundations but would be significant in terms of groundwater interaction with wetlands.

All potential NPS liquid emissions entering the groundwater system would tend to migrate towards the sea. However, the presence of a cut-off wall will contain any such contamination from the reactors in the primary aquifer to the footprint area. Gaseous emissions would be dispersed by the prevailing winds but would be at low concentrations from normal operations.

Seawater intrusion is likely in the vicinity of the NPS footprint under dewatering conditions, depending on set-back distance from the coast and position of the cut-off wall.

2.2 Bantamsklip

2.2.1 Extent and Physiographic Setting

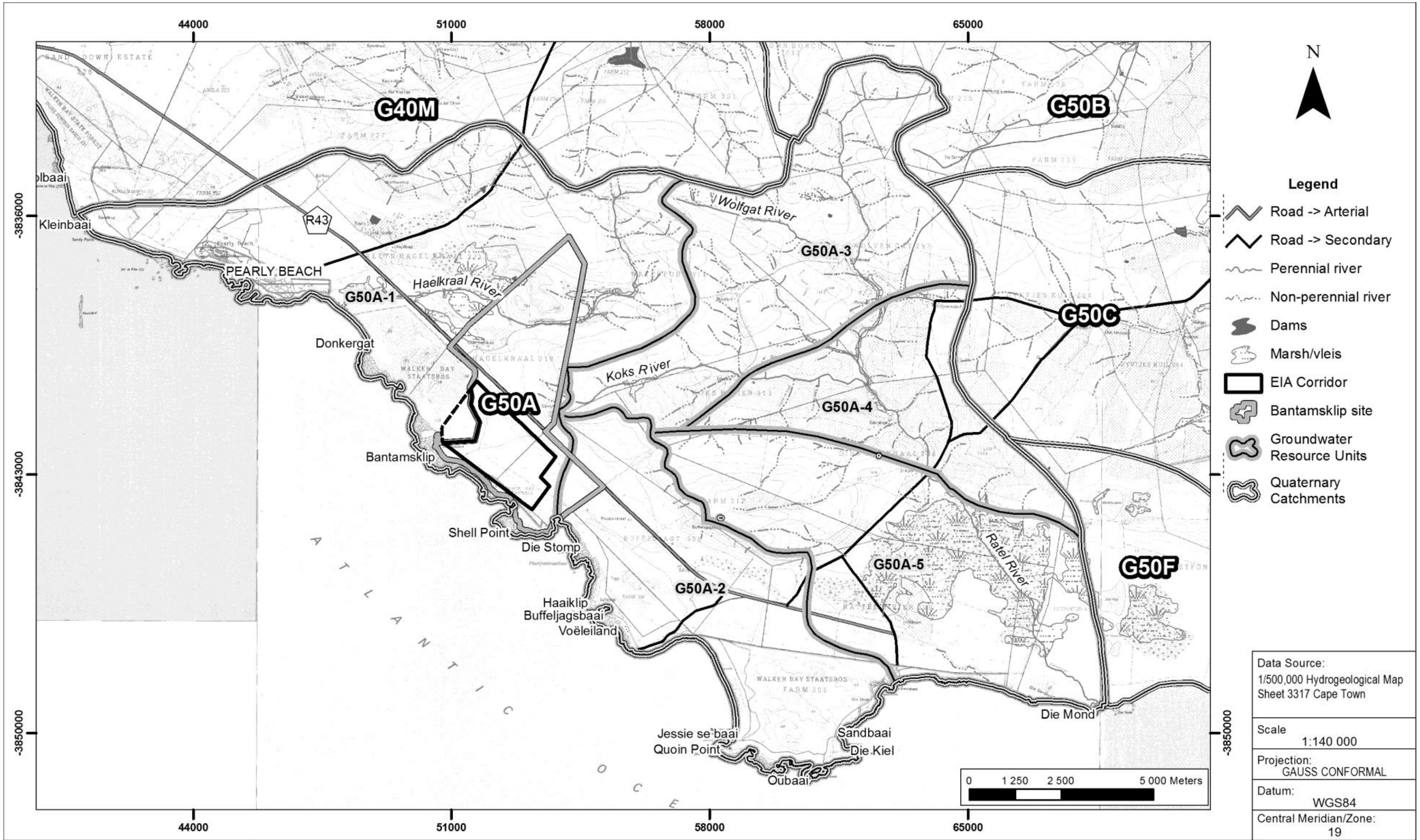
The Bantamsklip site is located along the coast approximately mid-way between Danger Point and Quoin Point (
Figure 2.27). It is located within the municipal boundaries of the Overberg Municipality, and is situated partially on Farm No. Re/318 Groot Hagelkraal and partially on Farm No. 1/318, which falls within the Walker Bay Nature Conservation Area and about 7 km south-east of the holiday town of Pearly Beach. Access to the site is *via* a tarred road (R43) from Gansbaai. There is an access track running from the R43 at the western edge of the site down to and then along the coast, re-joining the R43 further to the east of the site.

The site falls within quaternary catchment G50A and occurs within the Breede WMA. The area has been subdivided into five GRUs based mainly on geology and surface drainage features, as well as the bedrock topography and groundwater flow regime in the case of the unconsolidated Cenozoic-age deposits. The site falls within the G50A-1 GRU.

The G50A-1 GRU extends from the source of the Haelkraal River in the north-east down to the coast and Peninsula Formation outcrops which occur along the coast. The eastern boundary is formed by the naturally occurring surface drainage boundary between the Haelkraal and Koks rivers. The GRU is predominantly covered by sediments of the Strandveld and Waenhuiskrans formations of the Bredasdorp Group. To the north, the site partially extends into the Walker Bay Nature Reserve which is managed by Cape Nature.

The topography is relatively flat with a gentle slope towards the coast. However, both ancient dunes stabilised by vegetation and Recent-age unconsolidated dunes with heights of <10 m are found along the coastline. The part of the site along and to the south-west of the tar road is situated on a coastal plain between 25 and 50 mamsl. The topography rises to the north-east to heights of between 150 and 200 mamsl. The coastal strip reveals a wave-cut platform developed on the bedrock, which is only exposed in a narrow rocky belt at the high-tide mark. The coastal belt becomes sandier to the south-east with less rock exposure.

No river channels drain the immediate site due to the presence of permeable sandy soils. However, the perennial Haelkraal, Koks, Wolfgat and Ratel rivers drain the broader study area. The Koks and Wolfgat rivers are tributaries of the Ratel River. These rivers all flow in a south-easterly direction towards the coast. Most of the smaller streams along the coast ‘disappear’ in the flat sandy areas near the ocean and do not maintain open river channels across the narrow raised dunes along the coast.



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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATIONAND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
LOCATION OF THE BANTAMSKLIP SITE

Date:	Compiled by:
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The site has a Mediterranean climate, thus in general the summers are dry and the main rainfall occurs in winter. However, precipitation may occur throughout the year. The average annual rainfall ranges between 400 and 600 mm/a. The Walker Bay Nature Reserve consists predominantly of Dune Shrub lands/Fynbos and hummocky Limestone Fynbos of the Thicket and Fynbos Biomes, respectively, while large parts of the Walker Bay Nature Reserve are heavily infested with invasive alien tree species such as Rooikrans (*Acacia Cyclops*).

2.2.2 Regional Groundwater Occurrence

A number of geological formations occur in the area of the site. Outcrops of the Hermanus Granite Pluton (
Figure 2.28) occur at the Donkergat headland at the eastern edge of Pearly Beach. The Table Mountain Group (TMG) consists mainly of quartzitic sandstone, with the Peninsula Formation being prominent in the study area. These rocks are exposed along the coast and in elevated areas to the north-east of Pearly Beach. Shale of the Bokkeveld Group occurs in a trough to the north of Bantamsklip, centred on Baardkeerdersbos.

The coastal plain is covered by sediments of the Bredasdorp Group. These sediments comprise semi-consolidated aeolian sand with calcrete lenses (Waenhuiskrans Formation) deposited on a wave-cut platform of TMG rocks. Unconsolidated sand with shell fragments (Strandveld Formation) occurs along the beach zones.

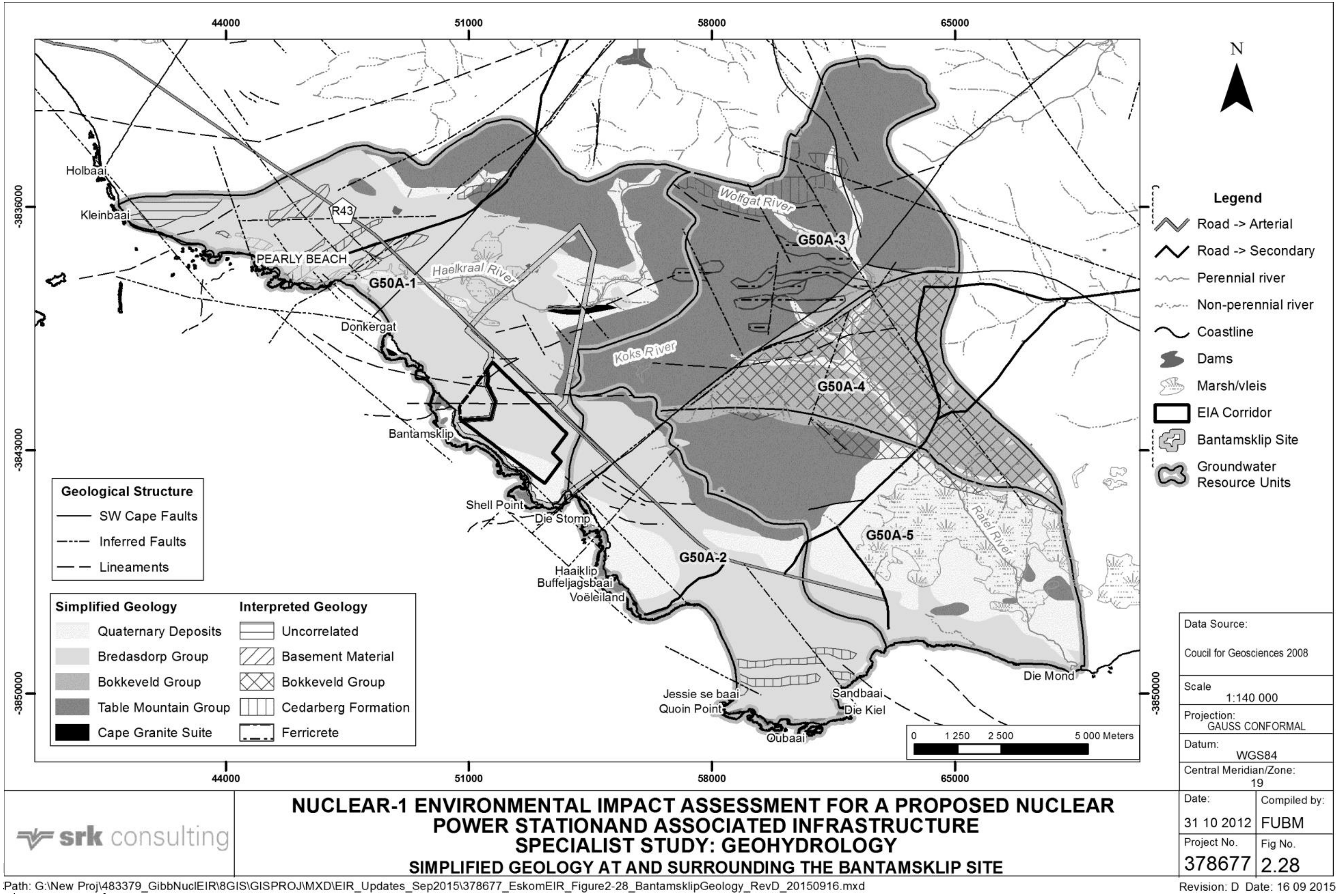
The bedrock at the site consists of the Cape Granite Suite and TMG sandstone, both of which can be broadly classified as secondary or fractured-rock type aquifers. Groundwater flow and storage takes place within secondary openings in the rocks formed by joints, faults and fractures. For the purpose of this assessment the secondary aquifers associated with these rocks are called the Granite Aquifer and TMG Aquifer, respectively. These rocks are covered by superficial deposits and so aquifers developed are likely to be semi-confined.

The superficial deposits of the Bredasdorp Group is classified as a primary or intergranular aquifer. Groundwater flow and storage takes place within the original pore spaces between constituent grains. The upper boundary of the aquifer is the water table and this aquifer is therefore unconfined. For the purpose of this specialist study the primary aquifer is called the Bredasdorp Aquifer.

2.2.3 Lithostratigraphy

The geological formations occurring in the area are indicated in **Table 2.13** and on Figure 2.28. A number of major northeast-southwest trending faults are mapped in the area.

The Malmesbury Group is not exposed in the study area (Johnson *et al.*, 2006). However, boreholes drilled during the geological investigation by the AEC (1989) along the main coastal tar road encountered blue-grey ‘baked’ shale, which is interpreted to be Malmesbury Group. It is assumed that the ‘baked’ or metamorphosed appearance of the shale is due to the proximity of the intrusive granite.



NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATIONAND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
SIMPLIFIED GEOLOGY AT AND SURROUNDING THE BANTAMSKLIP SITE
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Legend
Road -> Arterial
Road -> Secondary
Perennial river
Non-perennial river
Coastline
Dams
Marsh/vleis
EIA Corridor
Bantamsklip Site
Groundwater Resource Units
Geological Structure
SW Cape Faults
Inferred Faults
Lineaments
Simplified Geology
Quaternary Deposits
Bredasdorp Group
Bokkeveld Group
Table Mountain Group
Cape Granite Suite
Interpreted Geology
Uncorrelated
Basement Material
Bokkeveld Group
Cedarberg Formation
Ferricrete
Holbaai
Kleinbaai
PEARLY BEACH
R43
G50A-1
G50A-2
G50A-3
G50A-4
G50A-5
Haelkraal River
Koks River
Wolfgat River
Ratel River
Donkergat
Bantamsklip
Shell Point
Die Stomp
Haaiklip
Buffeljagsbaai
Voëleiland
Jessie se baai
Quoin Point
Oubaai
Sandbaai
Die Kiel
Die Mond
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51000
58000
65000
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-3850000
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Table 2.13: Geological Formations Present in the Bantamsklip Study Area

Group	Formation	Intrusive Rocks
Bredasdorp	Strandveld Waenhuiskrans	
Bokkeveld	Ceres	
Table Mountain	Peninsula	
Malmesbury	Tygerberg	Hermanus Granite Pluton

Bredasdorp Aquifer

The Bredasdorp Group of semi-consolidated aeolian sand with calcrete lenses (Waenhuiskrans Formation) is deposited on a wave-cut platform of TMG rocks. Unconsolidated sand with shell fragments (Strandveld Formation) occurs along the beaches. The Waenhuiskrans Formation varies in thickness from 4-6 m at the coast, to *c*.20 m at the R43 turn off to Pearly Beach and *c*.30 m in the north-eastern corner of the site. Boreholes drilled during the EIA phase indicate that the surficial deposits attain a thickness between 6 and 30 m. Saturated thickness is inferred to range between 0 and 17 m. At the site the saturated thickness ranges from 2 to 6 m, with a median of *c*.2 m. The majority of boreholes drilled into the Bredasdorp Aquifer were dry.

Table Mountain Group Aquifer

The TMG consists mainly of quartzitic sandstone of the Peninsula Formation in the study area. These rocks are exposed along the coast and in the more elevated area to the north-east of Pearly Beach. The drilling programme undertaken for this assessment indicates that, at the coastal plain and wave cut platform, the TMG Aquifer is intersected at depths of between 6 and 9 mbgl (**Table 2.14**). Further inland this depth increases to between 14 and 30 mbgl.

Granite Aquifer

Outcrops of the Hermanus Granite Pluton occur at the Donkergat headland at the eastern edge of Pearly Beach and further inland along the Haelkraal River on the farm Groot Hagelkraal. The granite body is composed of coarse-grained porphyritic granite interspersed with fine- to medium-grained biotite granite. Three of the boreholes intersected granite at depths of 6, 9 and 23 mbgl (**Figure 2.29**).

2.2.4 Hydraulic Properties

Bredasdorp Aquifer

From the available pump test data, an average T value of 5 m/d and S of 0.16 have been derived (see **Table 2.15**). These are relatively low values.

Table 2.14: Summary of Lithological Information for Bantamsklip

BH ID	X	Y	DEM Elevation (mamsl)	Collar Elevation (mamsl)	Depth (m)	Steel Casing (m)	Bredasdorp Group base (mbgl)	Peninsula Formation (mbgl)	Cape Granite (mbgl)
BP1	-3841825	50714	16.21	16.43	42	6	6	42	
BP2	-3842306	50674	9.56	9.81	36	6	6	36	
BP3	-3842591	50997	6.35	6.65	36	6	6	36	
BP4	-3842321	53079	38.39	38.82	100	24	19	100	
BP5	-3842924	52468	20.09	20.37	75	18	14	75	
BP6	-3840678	52070	39.84	40.41	101	24	21	102	
BP7	-3842321	51741	20.59	20.77	48	9	18	48	
BP8	-3841487	51953	33.99	34.27	60	24	22	60	
BP8_ObN	-3841472	51953	34.13	34.43	60	19	21	60	
BP8_ObW	-3841497	51926	33.50	33.88	36	20	17	36	
BP10	-3843339	55107	40.13	40.45	100	34	30	100	
BP12	-3839003	54050	60.45	60.89	100	36	6		100
BP13	-3837606	54118	98.87	99.25	100	54	23		100
BP15	-3838958	51518	23.89	24.29	60	18	9	11	60
BP16	-3840555	53797	90.55	90.75	102	54	20	100	
BP17	-3839565	52720	36.32	36.70	100	18	14	100	
BP20	-3842448	50767	8.41	8.86	36	9	9	36	
BP21	-3841121	51490	33.76	34.06	60	24	21	60	
BP24	-3842477	51394	11.35	11.60	42	7	7	42	

Table 2.15: Summary of Bredasdorp Aquifer Parameters for the Bantamsklip Site

BH No.	T (m^2/d)	S_y	Assumed K (m/d)	Assumed Porosity (%)	Maximum Test Yield (L/s)	Recommended Sustainable Yield (L/s)	Comments
BP9	-	-	10	30	Dry	-	Borehole dry
BP11	-	-	10	30	Dry	-	Borehole dry
BP19	5	3.3×10^{-3}	10	30	1.00	0.30	Sustainable yield calculated with FC, CJ & Theis Methods
BP25	-	-	10	30	Dry	-	Borehole dry
BP26	4	1.6×10^{-1}	10	30	0.59	0.20	Sustainable yield calculated with FC, CJ & Theis Methods
BP27	0.3		10	30	0.03	0.01	Borehole too weak to pump test properly
BP28	5	1.5×10^{-1}	10	30	1.00	0.30	Sustainable yield calculated with FC, CJ & Theis Methods
Average	3.6	1.6×10^{-1}	10	0.3	0.70	0.20	

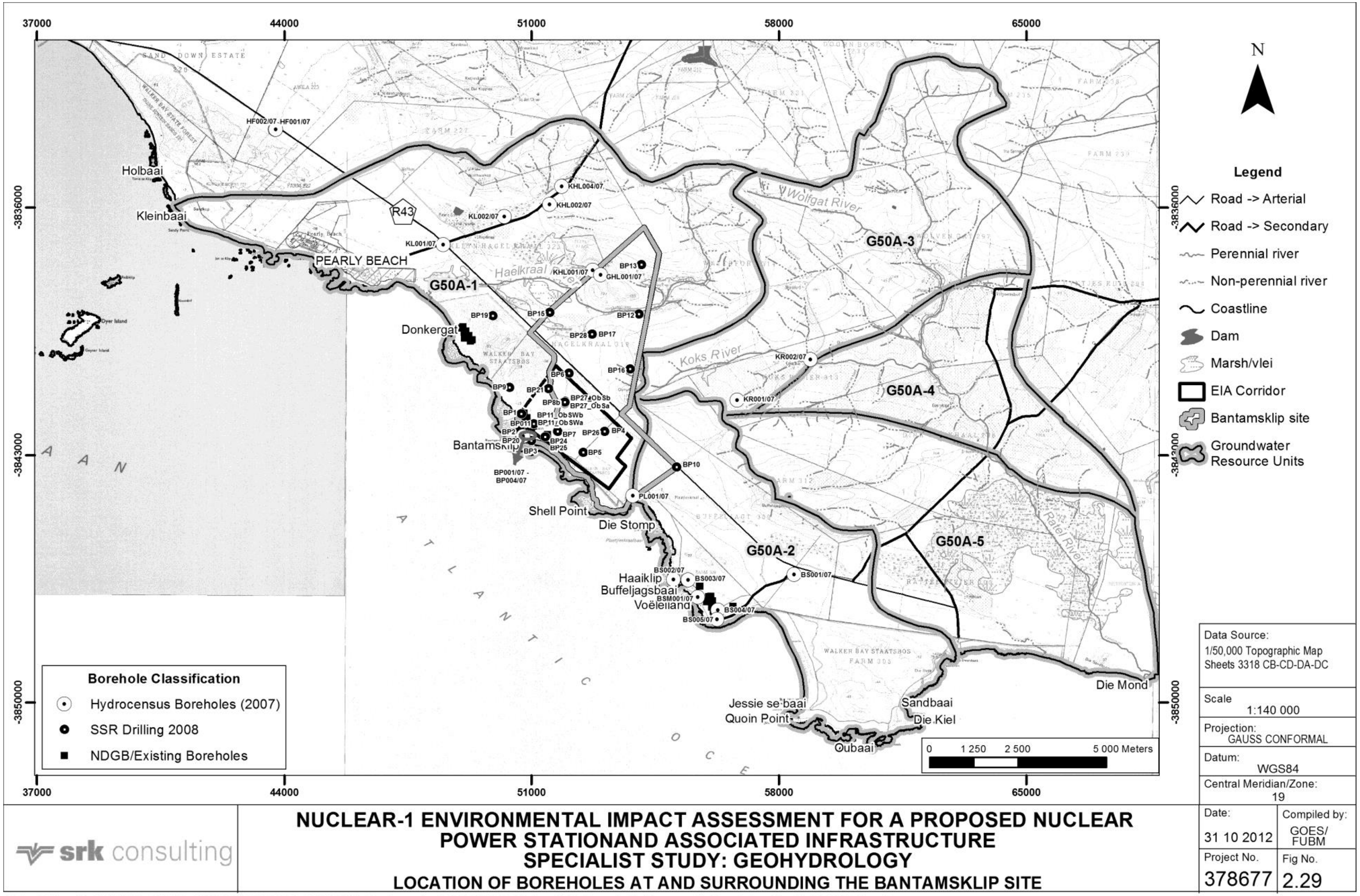

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Table Mountain Group Aquifer

Analysis of the pumping test data indicates leaky aquifer conditions at most of the boreholes. This is indicative of leakage from the overlying Bredasdorp Aquifer into the TMG Aquifer under pumping conditions. Using various analytical methods (FC, Cooper-Jacob and Walton), T values was calculated to range from 1 to 6 m^2/d with a median value of *c*.4 m^2/d (**Table 2.16**). Similarly, S was calculated to range from 1.6 x 10^{-3} to 2.1 x 10^{-3} with a median of 1.8 x 10^{-3}.

Granite Aquifer

The T for the granite is expected to be very low and in the order of <1 to 3 m^2/d (Meyer, 2001). The data derived from the test pumping conducted on BP15 yield very low T values of 0.3 m^2/d and S of 5.2 x 10^{-4} (**Table 2.17**) in line with the above prediction.

2.2.5 Borehole Yields

Bredasdorp Aquifer

The Bredasdorp Aquifer is classed as having a median borehole yield of 0.5 to 2.0 L/s, excluding dry boreholes (
Figure 2.30) (Meyer, 2000). Pumping tests conducted show yields within this range, i.e. <1 L/s (see **Table 2.15**).

Table Mountain Group Aquifer

The TMG Aquifer in the area is classed as having median borehole yields of 0.5 to 2.0 L/s, excluding dry boreholes (Meyer, 2000). Previous studies have estimated yields to range between 0.5 and 1.2 L/s (Levin, 1998).

Analysis of the pump test data indicates that the TMG Aquifer in the study area is generally low yielding with long term yields ranging between 0.05 and 1 L/s, with a median of 0.25 L/s. Maximum pump yields achieved during the step drawdown tests ranged from 0.12 to 3.12 L/s, with a median yield of 0.91 L/s (**Table 2.16**).

Granite Aquifer

It is often difficult to develop boreholes with strong yields in the Cape Granite Suite due to:

- Lack of weathering;
- Permeability inhibiting substances produced by weathering;
- Lack of joints and fractures.

Groundwater is encountered in the fractured and weathered granite, but yields in excess of 1 L/s are uncommon (Meyer, 2001). An analysis of yield frequencies of 449 boreholes in the Cape Granite Suite (Meyer, 2001) showed that 42 per cent of boreholes yield <0.5 L/s, while only 5 per cent yield >5 L/s. These low yields are confirmed by the results of the three boreholes drilled into the granite during the fieldwork. Pumping tests indicate maximum yields ranging between 0.11 and 0.30 L/s, with a median of 0.20 L/s, which is very low (**Table 2.17**). Sustainable yields are even lower and estimated to be 0.07 L/s or less.

Table 2.16: Summary of TMG Aquifer Parameters for the Bantamsklip Site

BH No.	T (m^2/d)	S	K assumed for FC (m/d)	Assumed Porosity (%)	Maximum Test Yield (L/s)	Recommended Sustainable Yield (L/s)	Comments
BP1	-	-	0.1	10	0.62	0.02	Sustainable yield estimated from Calibration Graph
BP2	-	-	0.1	10	0.73	0.03	Sustainable yield estimated from Calibration Graph
BP3	-	-	0.1	10	0.50	0.10	Sustainable yield estimated from Calibration Graph
BP4	1	2.1×10^{-3}	0.1	10	1.33	0.20	Sustainable yield calculated with FC-Method
BP6	-	-	0.1	10	1.62	0.30	Sustainable yield estimated from Calibration Graph
BP7	4	1.6×10^{-3}	0.1	10	3.12	1.00	Sustainable yield calculated with FC-Method
BP8	4	1.7×10^{-3}	0.1	10	3.12	0.30	Sustainable yield calculated with FC-Method
BP10	-	-	0.1	10	0.71	0.10	Sustainable yield estimated from Calibration Graph
BP16	-	-	0.1	10	0.12	0.05	Sustainable yield estimated from Calibration Graph
BP17	-	-	0.1	10	1.01	0.30	Sustainable yield estimated from Calibration Graph
BP20	4	1.6×10^{-3}	0.1	10	1.84	0.70	Sustainable yield calculated with FC-Method
BP21	-	-	0.1	10	0.60	0.10	Sustainable yield estimated from Calibration Graph
BP24	6	1.8×10^{-3}	0.1	10	1.13	0.50	Sustainable yield calculated with FC-Method
Average	4	1.8×10^{-3}	0.1	10	1.23	0.29	
Median	4	1.8×10^{-3}			0.91	0.25	

Table 2.17: Summary of Granite Aquifer Parameters for the Bantamsklip Site

BH No.	T (m^2/d)	S	K Assumed for FC (m/d)	Assumed Porosity (%)	Maximum Test Yield (L/s)	Recommended Sustainable Yield (L/s)	Comments
BP12	-	-	1.0×10^{-3}	1	0.11	0.05	Sustainable yield estimated from Calibration Graph
BP13	-	-	1.0×10^{-3}	1	0.20	0.05	Sustainable yield estimated from Calibration Graph
BP15	0.3	5.2×10^{-4}	1.0×10^{-3}	1	0.30	0.07	Sustainable yield calculated with FC-Method
Average	0.3	5.2×10^{-4}	1.0×10^{-3}	1	0.20	0.06	
Median	0.3	5.2×10^{-4}	-	-	0.20	0.05	

Based on the determined low sustainable yields, there are no viable aquifers at the site.

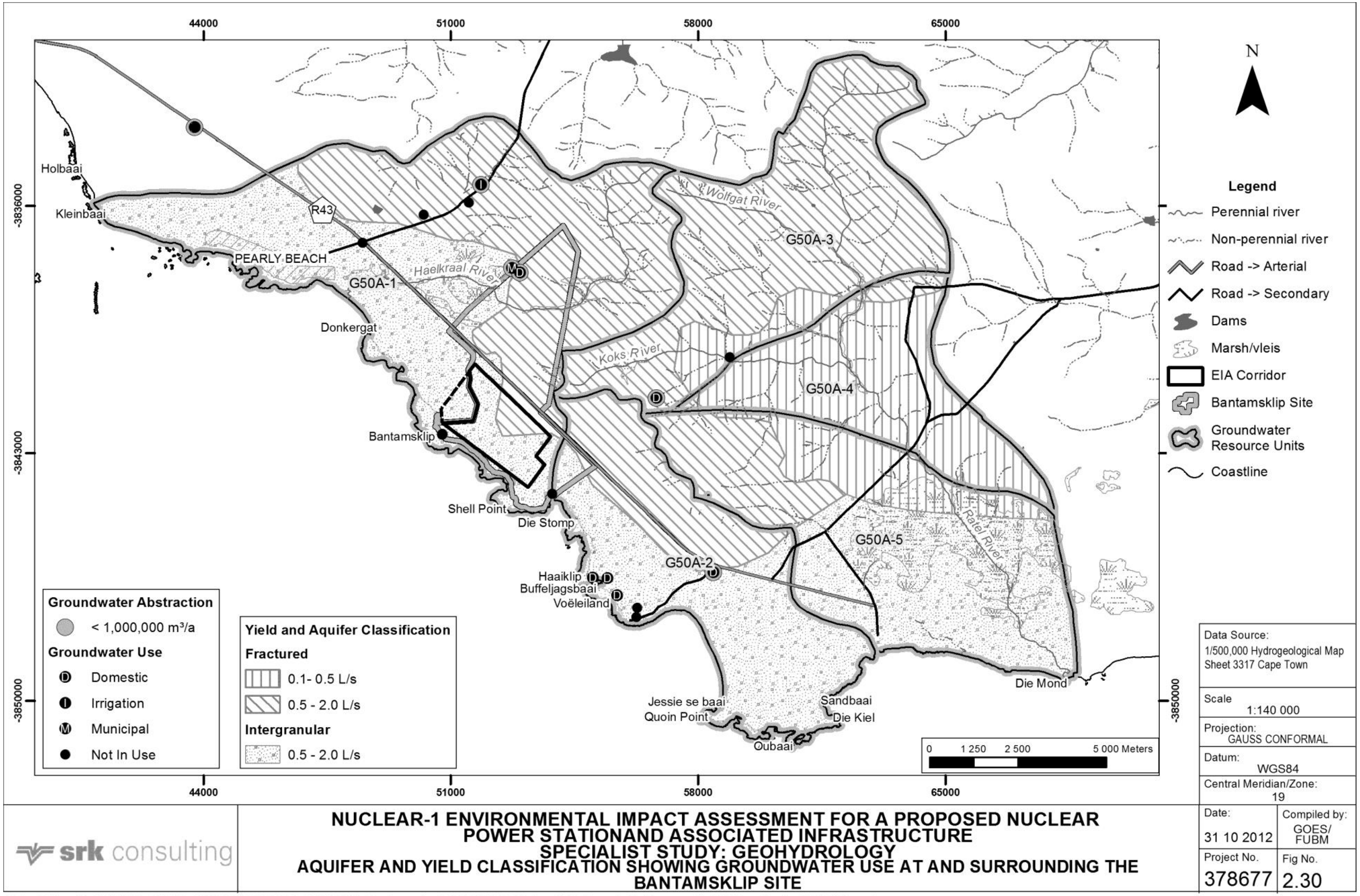
2.2.6 Recharge

The study area was subdivided into GRUs based on the identified surface water drainage systems and geohydrological considerations (
Figure 2.31). The GRUs represent areas where the broad geohydrological characteristics, i.e. water occurrence and quality, hydraulic properties, flow regime, aquifer boundary conditions are anticipated to be similar.

The effective aquifer recharge was estimated for each GRU. Effective recharge refers to the amount of rainwater that infiltrates into the vadose zone and then actually passes into the underlying aquifer. The effective recharge in the study area is estimated to range between 5.3 (dry years) and 9.7 Mm^3/a (wet years) with an estimated mean of 7.5 Mm^3/a, which equates to an average recharge rate of *c*.5.5 per cent of MAP. This rate is within the range of recharge expected for the area. The variability of the mean annual groundwater recharge within the GRUs is summarised in **Table 2.18** and illustrated in
Figure 2.31.

Table 2.18: Mean Annual Effective Recharge from Rainfall for the Bantamsklip Site

GRU	Area	MAP	Mean Recharge	Mean Recharge	Recharge Factor	Wet Season		Dry Season		Range
						Mean Recharge	Upper Recharge	Mean Recharge	Mean Recharge	Mean Recharge
	(km^2)	(mm/a)	(m^3/a)	(mm/a)	(%)	(m^3/a)	(mm/a)	(m^3/a)	(mm/a)	(m^3/a)
G50A-1	81.5	550	2 507 647	30.8	5.6	3 242 178	39.8	1 769 203	21.7	1 472 975
G50A-2	40.0	544	1 207 290	30.2	5.5	1 570 754	39.2	856 755	21.4	713 999
G50A-3	47.4	545	1 500 727	31.7	5.8	1 944 671	41.1	1 056 806	22.3	887 866
G50A-4	26.7	540	745 488	28.0	5.2	965 588	36.2	525 607	19.7	439 981
G50A-5	50.8	537	1 505 615	29.6	5.5	1 954 003	38.5	1 064 134	21.0	889 869
TOTAL	246.4		7 466 767			9 677 194		5 272 505		4 404 690
AVERAGE		543			5.5					



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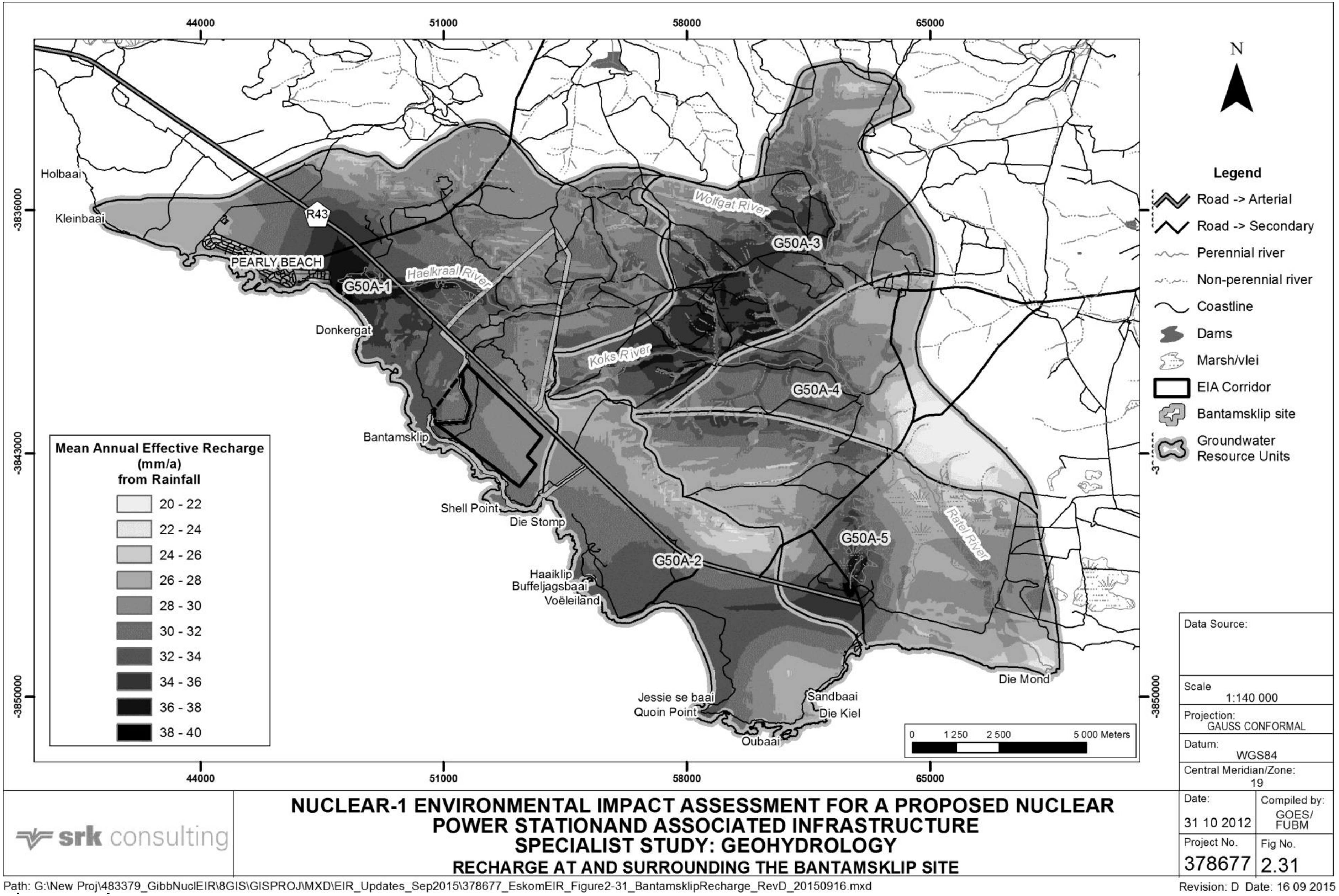
44000
51000
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N
Legend
Road -> Arterial
Road -> Secondary
Perennial river
Non-perennial river
Coastline
Dams
Marsh/vlei
EIA Corridor
Bantamsklip site
Groundwater Resource Units
Holbaai
Kleinbaai
R43
PEARLY BEACH
G50A-1
Haelkraal River
Wolfgat River
G50A-3
Donkergat
Koks River
G50A-4
Bantamsklip
Shell Point
Die Stomp
G50A-5
Ratel River
G50A-2
Haaiklip
Buffeljagsbaai
Voëleiland
Die Mond
Jessie se baai
Quoin Point
Sandbaai
Die Kiel
Oubaai
0 1 250 2 500 5 000 Meters
Mean Annual Effective Recharge (mm/a) from Rainfall
20 - 22
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Data Source:
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Central Meridian/Zone: 19
Date: 31 10 2012
Compiled by: GOES/ FUBM
Project No. 378677
Fig No. 2.31
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2.2.7 Depth to Groundwater

Bredasdorp Aquifer

Groundwater levels in the Bredasdorp Aquifer range from *c*.3 mbgl close to the coast, to between *c*.7 and 8 mbgl inland and to between *c*.0 and 3 mbgl near the Haelkraal River north of the R43 (**Table 2.19**). In some areas there is no groundwater in the sediments of the Bredasdorp Group and the boreholes drilled are dry, e.g. BP11, BP11ObSWb and BP25, all which are in the EIA Corridor Area. Two additional boreholes (BP-WBMR-1 and -2) were installed during February 2010 in the Bredasdorp Aquifer adjacent to the Haelkraal River and wetland system north of the R43 on Eskom's property. In addition, two piezometers (BP-WP1 and –WP2) were also installed in the wetland. The purpose of these additional boreholes and piezometers is to monitor the wetland/aquifer interaction over time. **Figure 2.32** shows the groundwater fluctuation at the site from January 2009 until June 2012, with boreholes BP19, BP27, BP- WBMR-1 and -2 representing the Bredasdorp Aquifer, whilst BP-WP1 and -WP2 represent the wetland. Seasonal water level fluctuations in the Bredasdorp Aquifer are small, ranging from approximately 0.2 to 0.6 m with no major variations evident. *Note: The Bredasdorp Aquifer on the site near the coast is mostly unsaturated*.

Table 2.19: Summary of Groundwater Levels in the Bredasdorp Aquifer, Bantamsklip Site

BH ID	Water Strike (mbgl)	Initial Groundwater Level (mbgl)	Initial Groundwater Level Elevation (mamsl)	EC (mS/m)	pH
BP2_ObsNE	Unknown[A]	Dry	N/A	N/A	N/A
BP9	Unknown[A]	Dry	N/A	N/A	N/A
BP11	Unknown[A]	Dry	N/A	N/A	N/A
BP11_ObSWa	Unknown[A]	Dry	N/A	N/A	N/A
BP11_ObSWb	Unknown[A]	Dry	N/A	N/A	N/A
BP19	Unknown[A]	7.83	9.17	105	7.90
BP25	Unknown[A]	Dry	N/A	N/A	N/A
BP26	Unknown[A]	7.00	24.25	80	8.5
BP27	Unknown[A]	11.66	17.97	127	8.5
BP27_ObSa	Unknown[A]	14.52	15.76	?	?
BP27_ObSb	Unknown[A]	Dry	N/A	N/A	N/A
BP28	Unknown[A]	3.15	34.23	50	7.7
A = Water strikes could not be determined due to mud-rotary drilling method used					

Table Mountain Group Aquifer

Groundwater in the TMG Aquifer is generally of a deep-seated nature inland but on the coastal plain and wave cut platform at the site the groundwater levels are within ~5 m of ground surface. Groundwater levels range between 2.6 mbgl (BP2) at the shoreline to 47.9 mbgl (BP16) further inland (**Table 2.20**). The former shallow level is the result of the groundwater at the site being at the end of its flow path with the site being very close to the coastline, i.e. located in a groundwater discharge zone. The influence of tides may impact on temporal variations in groundwater levels.

Figure 2.32 shows the groundwater fluctuation at the site from January 2008 to June 2012, with boreholes BP1, BP20 and BP24 representing the TMG Aquifer. No major water level fluctuations are evident and the single variation in September 2008 and July 2009 for borehole BP20 represents a severe storm event, which resulted in above normal wave action near the borehole. Note that this borehole is located close to the shoreline.

Granite Aquifer

Groundwater was encountered in the three boreholes drilled into the Cape Granite Suite. At BP12 the initial groundwater level was at 6.86 mbgl while at BP13 groundwater level was at 19.45 mbgl (**Table 2.21**). At BP15 the groundwater level is at 4.06 mbgl. Further inland the depth of the groundwater in the granite is deeper, up to *c.*20 mbc.

2.2.8 Direction of Groundwater Flow

The water table generally mimics the topography and is influenced by major drainage lines and dams. Groundwater in the TMG is generally of a deeper-seated nature (*c*.20 mbgl) inland but on the coastal plain and wave-cut platform at the site it is <5 m below ground surface.

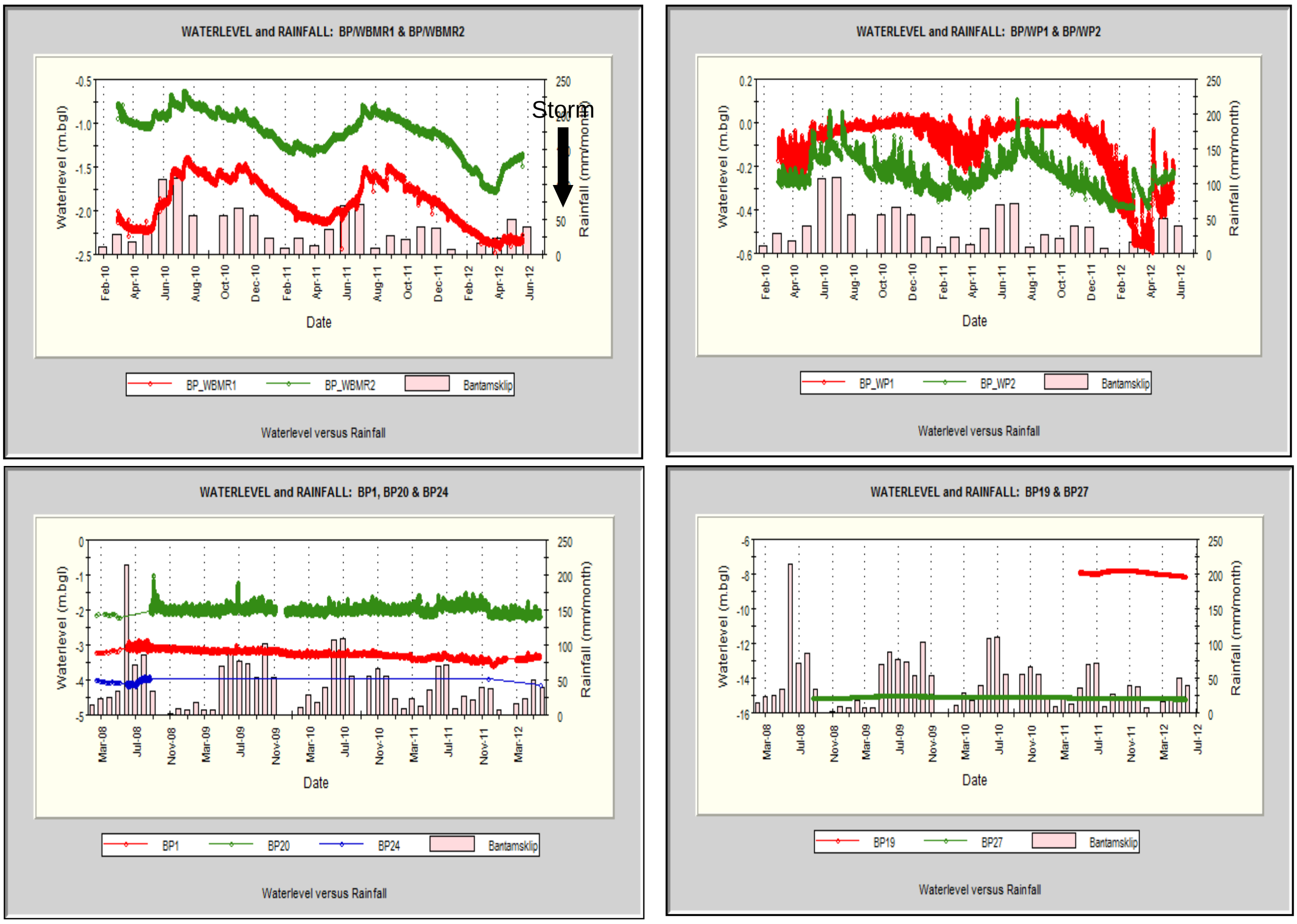
Local 'aquifers' are unconfined or semi-confined and groundwater flow will generally follow the topographic gradient. In general, flow is in a south-westerly direction towards the sea becoming more southerly closer to the Haelkraal River (
Figure 2.33).

The wetlands are fed by the Haelkraal River and lose water to the deeper groundwater table of the Bredasdorp Aquifer.

2.2.9 Hydraulic Gradient

The average hydraulic gradient from inland to the coast changes from 0.02 (1:50) in the high-lying areas to 0.005 (1:200) in flat coastal plain and again to 0.02 (1:50) near the coast. The hydraulic gradient changes from 0.033 (1:30) in the east to 0.025 (1:40) in the west.

Figure 2.32: Water Level vs Rainfall at Bantamsklip for Wetland Boreholes (top row), Wetland Piezometers (middle row), SSR TMG Aquifer (bottom left) and SSR Bredasdorp Aquifer (bottom right)



2.2.10 Rate of Groundwater Flow

Bredasdorp Aquifer

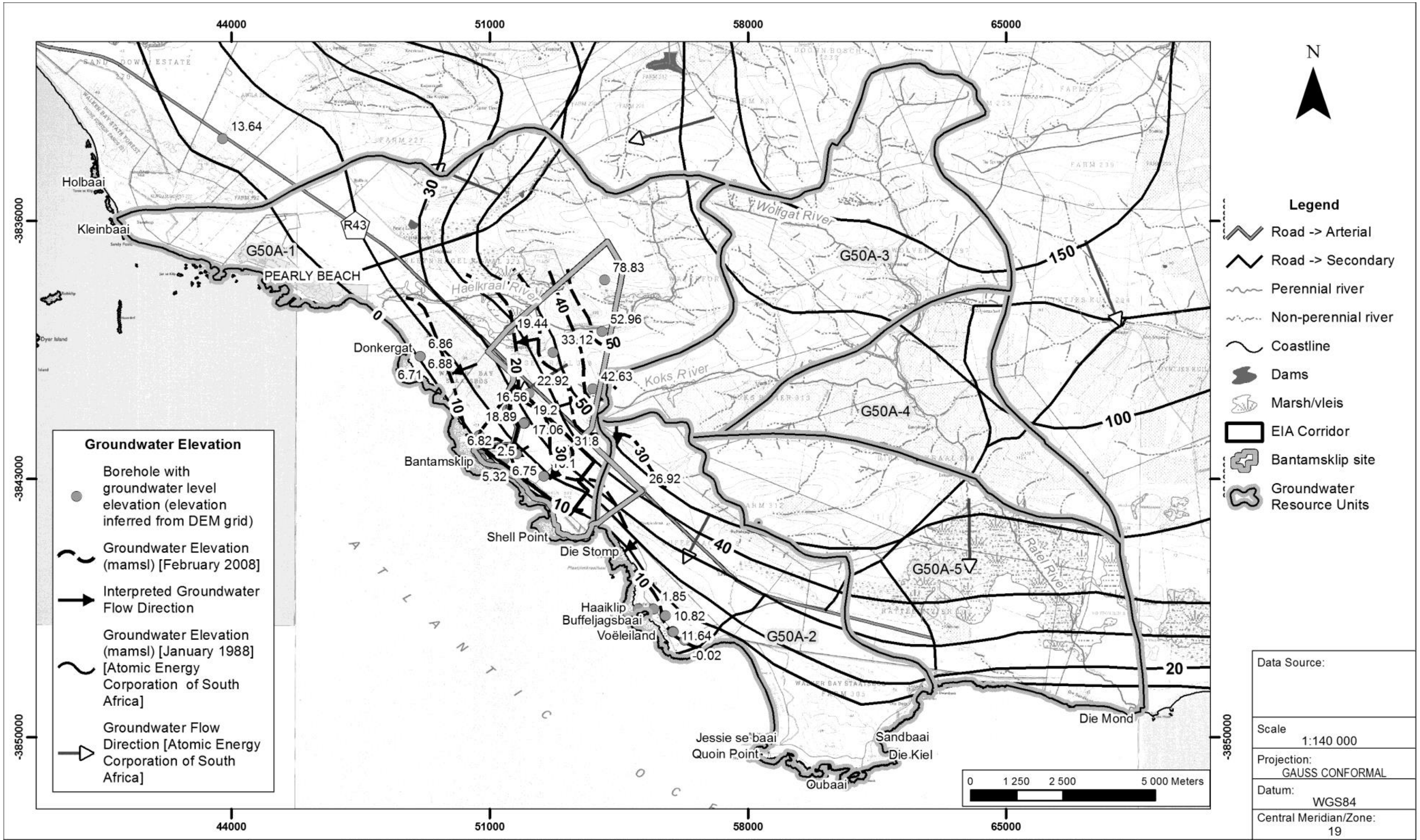
Based on the work conducted, groundwater flow velocities in the Bredasdorp Aquifer are estimated to range from *c*.0.7 m/d in the higher lying area in north-east, to *c*.0.2 m/d in the flat lying central area, to *c*.1 to *c*.1.7 m/d at the reactor footprint and towards the coast. Similarly, the flow velocity in the west changes from *c*.1 to *c*.0.8 m/d. The highest groundwater flow velocity determined in the area is from BP1 to the coast where a flow velocity of *c*.2.8 m/d was calculated.

Table 2.20: Summary of Groundwater Levels in the TMG Aquifer, Bantamsklip Site

BH ID	Water Strikes (mbgl)	Initial Groundwater Level (mbgl)	Initial Groundwater Level (mamsl)	EC (mS/m)	pH	Other
BP1	10-12, 16-17, 23-25, 30-32, 34-35, 39-40	3.54	1.97	91	7.47	
BP2	12-13, 24-26	2.62	1.00	392	7.25	Pebbles at 3 m. Water seep
BP3	5-6, 13-14, 16-18, 30-32	3.73	1.24	141	7.5	
BP4	10-19, 95	6.13	25.22	98	6.91	Minor water seep at 19 m
BP5	65	9.70	7.34	65	7.21	Minor water seep at 14 m
BP6	30, 88	16.39	13.91	104	6.98	Fracture/Fault Zone from 64-86 m. Minor water seep at 21 m
BP7	32, 40-42	8.69	8.30	118	7.67	
BP8	30-31, 48-50	14.91	15.09	58	7.15	First water seep at 22-24m in Bredasdorp Formation
BP8_ObN	36-37, 42-44, 48-52	14.73	14.67	60	7.55	Water strikes at 36-37 m, 42-44 m, 48-52 m. V-notch 45 mm
BP8_ObW	28-32	15.96	13.32	80	7.35	Water strikes at 28-32m with a v-notch = 60mm
BP10	30	12.88	28.94	60	7.66	Water strike was at the base of the overburden and the Sandstone
BP16	54-56	47.92	45.91	45	6.67	Weathered Ferruginised Sandstone horizon at 20-29 m
BP17	14, 54, 61	2.60	34.72	80	7.66	Yield determined at the base of the overburden in weathered zone *c*.3 L/s at 14 m
BP20	29	2.72	0.58	117	7.86	First Water seep at 7-9 m
BP21	26-27, 31-34, 41-44, 49-51, 54-56	16.90	11.07	67	7.68	
BP24	24, 36-39	4.39	4.76	186	7.69	Water strike at contact of the Bredasdorp Formation and Peninsula Sandstone

Table 2.21: Summary of Groundwater Levels in the Granite Aquifer, Bantamsklip Site

BH ID	Water Strike (mbgl)	Initial Groundwater Level (mbgl)	Initial Groundwater Level (mamsl)	EC (mS/m)	pH	Other
BP12	35-36, 49-50, 75-76, 85-88, 90-91, 95-98	6.86	58.28	71	8.16	Water strike too low could not to record v-notch. More considered to be damp spots
BP13	42-44, 75-76, 89-92, 95-96	19.45	76.05	43	7.75	Water strikes considered to be water seeps. Too low for v-notch
BP15	19-23, 38-43	4.06	19.91	87	7.14	Water strikes considered to be water seeps. Too low for v-notch. Higher yield at base of the overburden and the top of the granite basement



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SPECIALIST STUDY: GEOHYDROLOGY

GROUNDWATER ELEVATION AND INTERPRETED DIRECTION OF FLOW AT AND SURROUNDING THE BANTAMSKLIP SITE

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Table Mountain Group Aquifer

Average groundwater flow velocities in the TMG Aquifer have been calculated to range from 0.01 m/d in the flat lying central area to 0.04 m/d at the provisional reactor footprint to 0.1 m/d at the coast. From east to west the flow velocity changes from 0.06 to 0.05 m/d. Flow velocities in narrow well-fractured fault zones are expected to be considerably higher, possibly on par with that of the Bredasdorp Aquifer. However, no such well fractured zones were intersected in any of the historically drilled test holes or holes drilled for this assessment.

Granite Aquifer

Groundwater flow velocities in the Granite Aquifer range from 0.001 to 0.002 m/d.

2.2.11 Groundwater Quality

Over most of the study area, groundwater quality in terms of EC is in the range of 70 to 300 mS/m. Better quality groundwater (EC <70 mS/m) is associated with the TMG in the mountains to the north. The EC level of the water issuing from the spring supplying Pearly Beach was measured as 38 mS/m in 1989 while an EC level of 57 mS/m was measured during a 2007 hydrocensus for this assessment.

Field measurements taken during drilling and the subsequent monitoring programme for this ranges as follows:

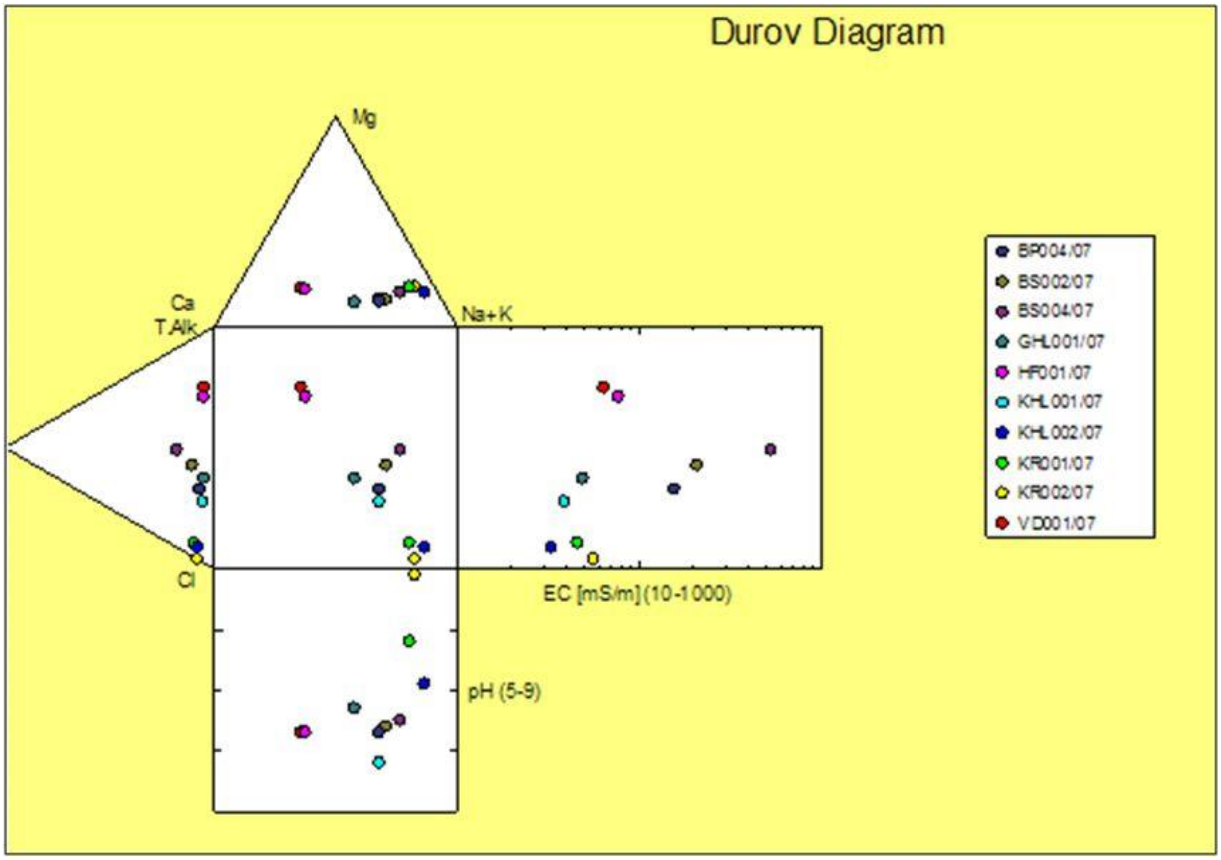
- Bredasdorp Aquifer: 50 to 400 mS/m;
- TMG Aquifer: 45 to 390 mS/m;
- Granite Aquifer: 45 to 85 mS/m.

An average EC level of 91 mS/m was measured in the TMG Aquifer during recent field investigations within a 5 km radius around the site. The maximum EC level measured was 186 mS/m) and a minimum EC of 45 mS/m. Moving further inland from the shore the salinity decreases (
Figure 2.36). The EC in groundwater at boreholes at the proposed Nuclear-1 footprint ranges between 91 mS/m and 186 mS/m.

The EC levels associated with the Granite Aquifer generally vary between 30 and 350 mS/m (Meyer, 2001). The results from the drilling programme show EC levels varying from 43 mS/m to 87 mS/m.

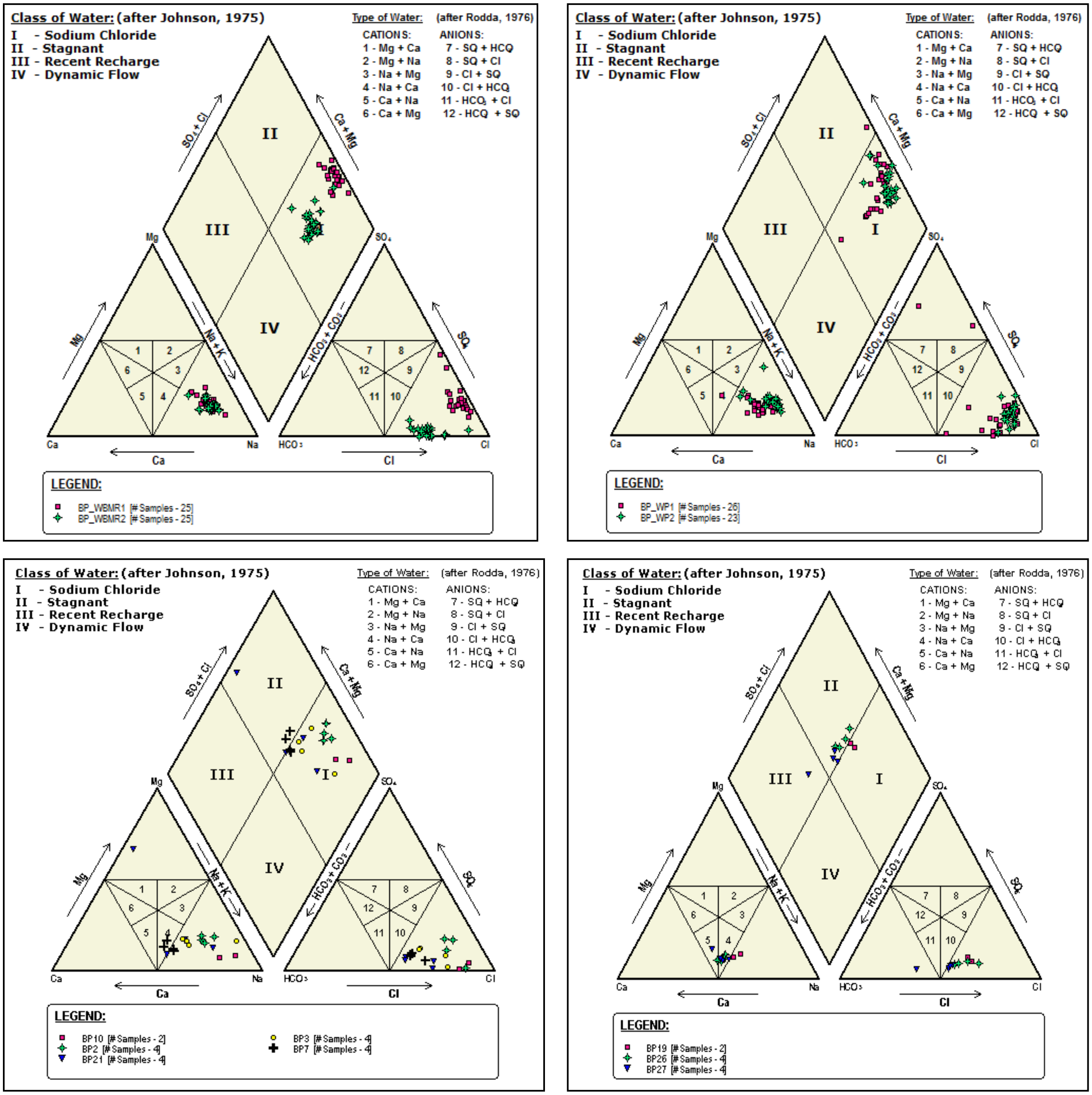
A Durov plot of the chemistry of all the samples taken during the hydrocensus boreholes is shown in **Figure 2.34** while those taken during the monitoring programme on a trilinear Piper plot in **Figure 2.35**. All the groundwater samples have a dominant Na/Cl-SO_4 character, as would be expected in a coastal environment. There is some SO_4 enrichment in a surface water sample at piezometer BP-WP1, possibly due to anaerobic conditions, which slow down the rate of vegetation decay in wetlands. The NaCl-signature is due to proximity to the ocean and local recharge from rainfall. The chemical character of the groundwater is very similar to that in other areas along the Southern Cape coast (AEC, 1989 and Levin and Joubert, 1985).

Figure 2.34: Durov Diagram Showing the Results of Macro Chemical Analyses for the Hydrocensus, Bantamsklip Site



The Langelier Saturation Indices of the water samples collected over the last six years vary from -3.2 to 0.5, indicating that this groundwater varies from being corrosive to scaling (some minor coating). Sulfate, which is aggressive towards ordinary concrete when present in concentrations >200 mg/L, ranges from 23 to 96 mg/L in the three boreholes closest to the enveloping footprint (BP19, BP26 and BP27) and the risk to foundations is therefore considered to be low. The Larson-Skold corrosion indices for mild steel for groundwater sampled from boreholes in the Bredasdorp Aquifer range from 0.7 to 2.7, with a median of 1.7, 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.

Figure 2.35: Piper Diagram Showing the Results of Macro-Chemical Analyses for the Water Samples from the Wetlands Boreholes (top left) Wetlands Piezometers (top right), SSR TMG Aquifer (bottom left) and SSR Bredasdorp Aquifer (bottom right), Bantamsklip site



Eleven water samples collected during the hydrocensus were submitted for ^{3}H, δD and δ^{18}O analysis (**Table 2.22**). Samples were also collected and submitted for ^{3}H, δD and δ^{18}O during the monitoring programme.

Table 2.22: Summary of Hydrocensus Stable Isotope and Tritium Analyses, Bantamsklip site

Borehole Name	Deuterium	Oxygen-18	Tritium	
	δD	**$\delta^{18}O$**	**TU**	**± ****
BS004/07	-25.6	-5.00	1.9	0.3
KHL001/07	-12.2	-2.76	1.7	0.3
BS002/07	-24.7	-4.67	1.2	0.3
KR001/07	-24.2	-4.96	1.7	0.3
VD001/07	-24.4	-4.74	1.8	0.3
KR002/07	-26.2	-5.38	0.1	0.2
HF001/07	-24.5	-4.73	2.3	0.3
BP004/07	-25.6	-4.95	0.7	0.2
KHL002/07	-21.9	-4.54	0.9	0.2
BS003/07	-23.1	-4.64	1.5	0.3
GHL001/07	-23.2	-4.74	1.1	0.2

** This is the counting statistic for a sample counting a total of 8 hrs

The low ^{3}H content indicates that the groundwater in the Bantamsklip area contains little or no recent water, i.e. post-1952 water (refer to **Subsection 2.1.6** for an explanation of the ^{3}H data analyses). Similar low ^{3}H were obtained during the monitoring programme (**Figure 2.37)**.

In terms of $\delta^{18}O$ and δD, the majority of the hydrocensus samples plot slightly above the GMWL, which is to be expected for a Mediterranean type climate (**Figure 2.38**). (Refer to **Subsection 2.1.11** for an explanation of $\delta^{18}O$ and δD data analysis). The samples generally show a uniform $\delta^{18}O$ of -4.65‰ with a variation of less than the analytical error of ±0.1‰.

This parallel line just above the GMWL is known as the Local Meteoric Water Line and indicates normal precipitation and recharge processes at the site and surrounding area. This indicates uniform and localized direct recharge. The sample taken from borehole KHL001/07 has a significantly different $\delta^{18}O$ of -2.76‰. This enrichment is possibly due to recharge from the nearby marsh or vlei. Samples KR001/07 and KR002/07 were taken at boreholes close to the origin of recharge indicating that the water has not been affected by mixing i.e. relatively young water. Samples BS004/07 and BP004/07 are located close to the shoreline which may have resulted in the slight enrichment of $\delta^{18}O$, -5.00‰ and -4.95‰, respectively.

The $\delta^{18}O$ and δD for the samples collected during the monitoring programme (up until June 2012) are plotted in **Figure 2.39**. The groundwater and wetland water samples plot parallel, close to and on the GMWL, indicating derivation predominantly from rainfall. Some of the BP-WP2 wetland water samples show enrichment, which could be due to evaporation.

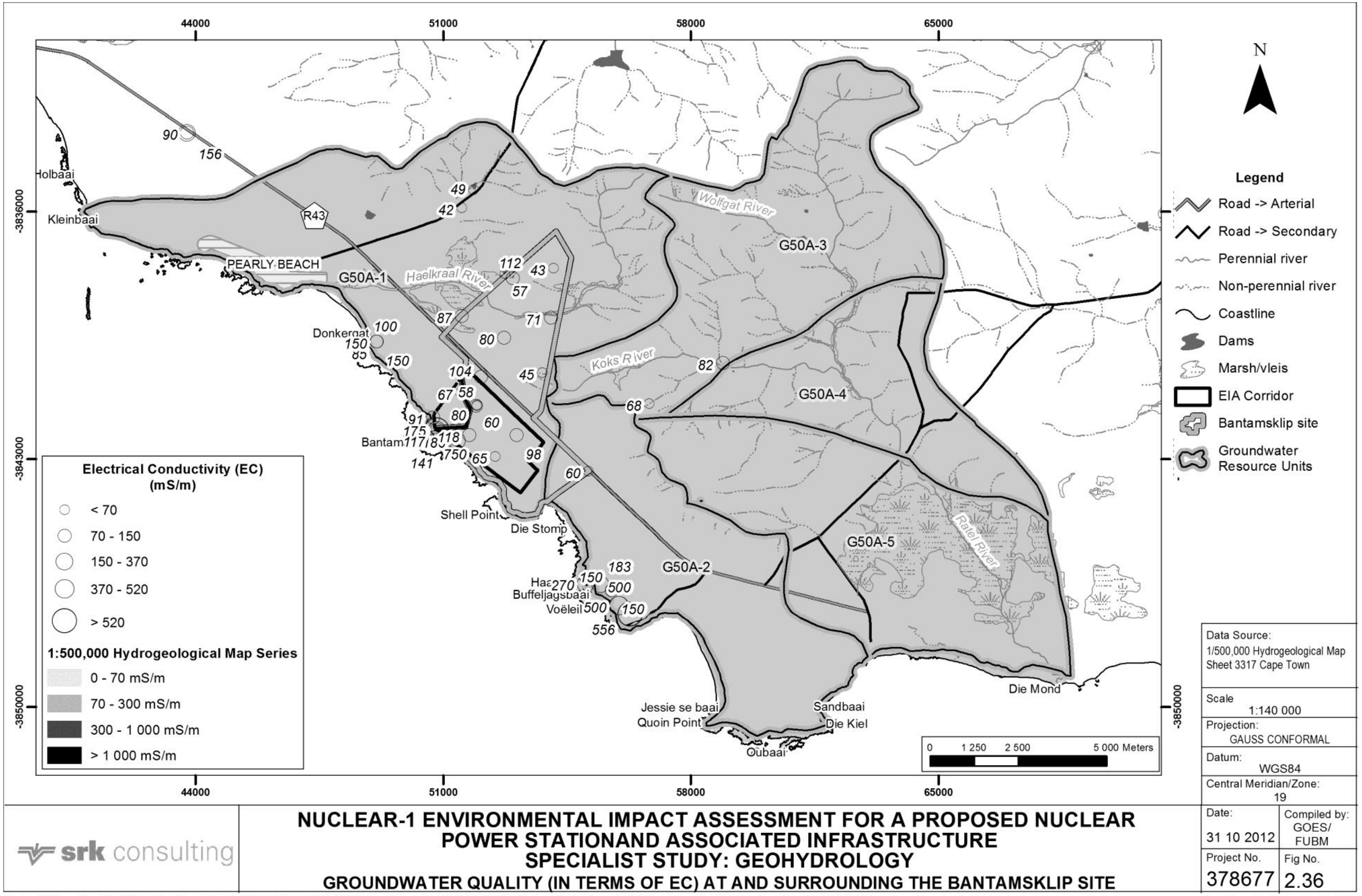


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Figure 2.37: Graph Showing Tritium Values for the Monitoring Boreholes, Bantamsklip Site

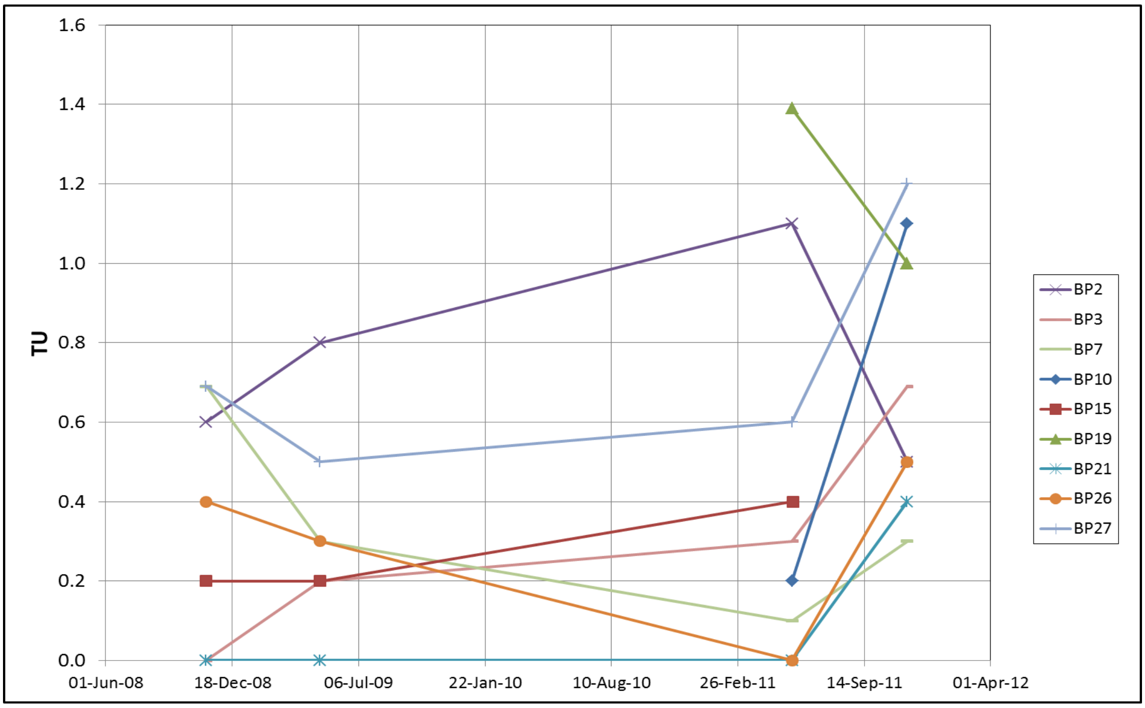


Figure 2.38: Analysis of δ18O versus δD for the Hydrocensus Boreholes, Bantamsklip Site

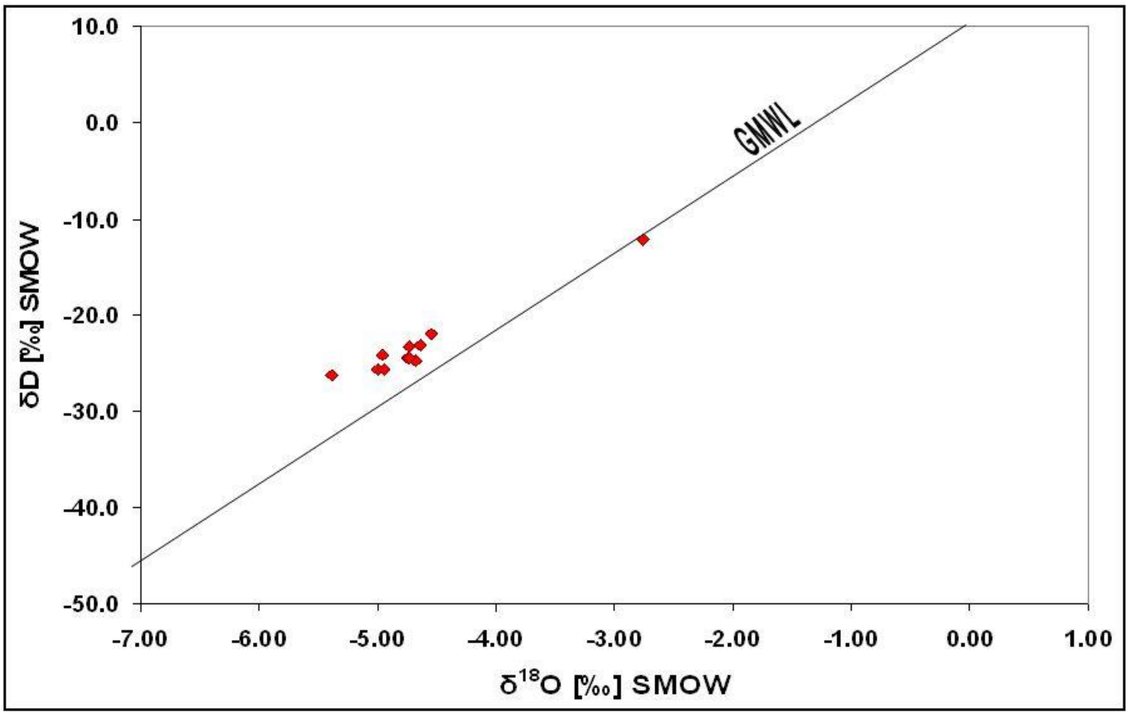
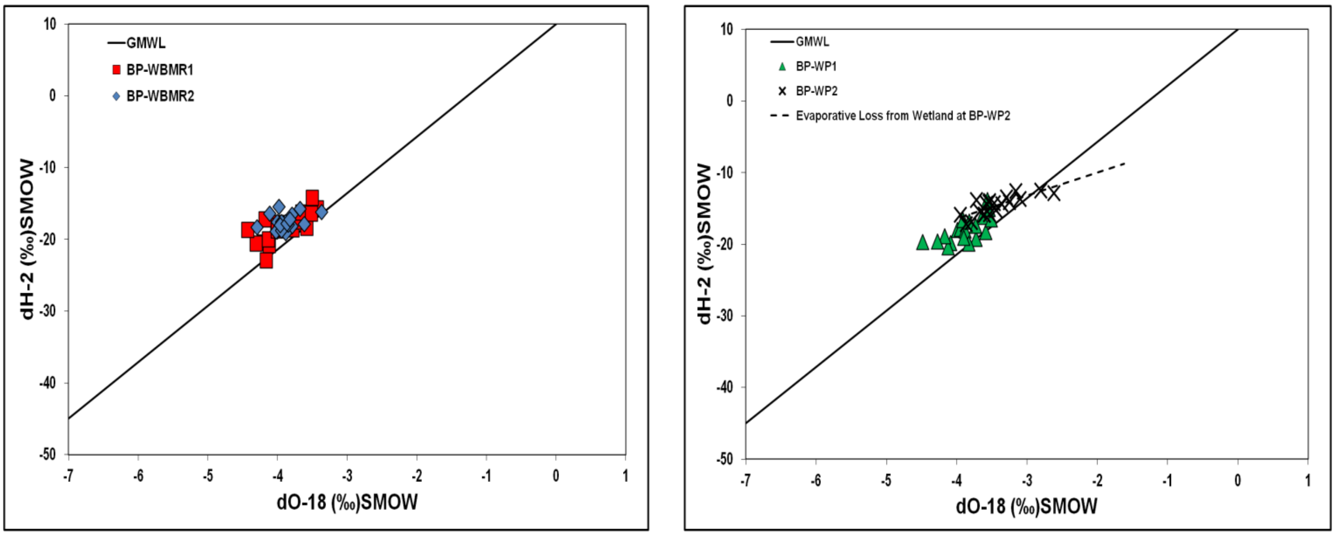


Figure 2.39: Analysis of δ18O versus δD for the Wetland Monitoring Boreholes (left) and Piezometers (right), Bantamsklip Site



2.2.12 Existing Groundwater Contamination

Based on site work carried out during this assessment, there appears to be no existing contamination at the site, which is located in a pristine area. As there are no existing contamination threats, the quality of groundwater at the site represents ambient conditions.

2.2.13 Potential Contamination Pathways

Local pathways for the migration of potential contaminants include the upper intergranular aquifer (Bredasdorp Aquifer) and the lower fractured-rock aquifer (TMG Aquifer). Any potential contamination releases occurring could migrate down-gradient through these aquifer systems. The extent of contamination would likely be restricted to within the site footprint and coastal springs / seeps, which may support sensitive ecosystems.

Leaks of any effluent, radioactive or otherwise, will not directly affect any existing groundwater users, but any air emissions from the site could be transported inland by prevailing winds (regional pathway) and contaminate groundwater by being incorporated into rainfall recharge. Such scenarios are highly unlikely.

2.2.14 Groundwater Use

Regional Groundwater Abstraction

Domestic water supply for Pearly Beach comes from springs (KHL001/07) located about 6 km to the north-east of the town. These springs issue from the Waenhuiskrans Formation and the yield has been estimated at >7 L/s (
Figure 2.30) (Meyer 2001). Buffeljags obtains its water from a municipal borehole BSM001/07 for which the rate of abstraction is unknown. Some of the home owners in Buffeljags and Pearly Beach also have their own private boreholes and dug wells from which small amounts of water (<10 m^3/d) mainly for garden irrigation are abstracted when necessary. Small amounts of groundwater (<10 m^3/d per borehole) are also being abstracted by some of the farms from boreholes and springs for stock watering and

general domestic use. Assuming that Pearly Beach uses the total spring-flow of 7 L/s and that *c*.20 private boreholes in quaternary catchment G50A abstract *c*.10 m^3/d each, it is estimated that the total groundwater abstraction from G50A is in the order of *c*.300 000 m^3/a.

On-site Groundwater Abstraction

The only groundwater use at the site is the small amount (<10 m^3/d) used by the Bantamsklip homestead, which is piped from a nearby spring.

Ecosystem Water Use and Interaction with Surface Water

The site includes extensive wetlands of high conservation importance, which feed into important downstream systems, such as the Pearly Beach Marsh and the Ratels River wetlands. Bantamsklip lies on the western side of the Agulhas Plain, which extends from the Klein River mouth to the Breede River. The Agulhas Plain is described as containing the largest and most diverse array of wetlands in the southern Western Cape with a high likelihood of supporting rare and/or endemic plant and animal species (King *et al.,* 1989). These wetlands exhibit exceptional diversity, in terms of both habitat type and biota. Conservation of the system in its entirety has been strongly recommended (Jones *et al.,* 2002).

Although several seasonal seepage wetlands are thought to occur on Bantamsklip south of the R43 Road (King *et al.*, 1989), the most ecologically important systems occur in the northern part of the site and include the upper reaches of the Koksrivier (a tributary of the Ratels River system) to the east and the Haelkraal River to the west.

The Haelkraal River merges with its westerly tributary, the Klein Haelkraal River, downstream of the R43 and west of the present study area. Immediately downstream of their confluence, the rivers form a wide, coastal lake, referred to as the Pearly Beach Marsh (Jones *et al.* 2002) and described as a site of Special Scientific Interest (King *et al.,* 1989), by virtue of the combination of different wetland types and substrata that characterise it. The site is classified as being of high regional and local importance from a botanical perspective (Euston-Brown, 2003) and in terms of wetland habitat importance (Day, 2005). Alien vegetation growth, as well as channelisation of the river downstream of the R43, has resulted in shrinkage and degradation of the Haelkraal riverine wetlands in these reaches, and a reduction in the species diversity upstream (Day, 2005). These wetlands, and in particular the less-impacted Pearly Beach Marsh / coastal lake and lagoon, are considered to have high habitat conservation value (Day, 2005).

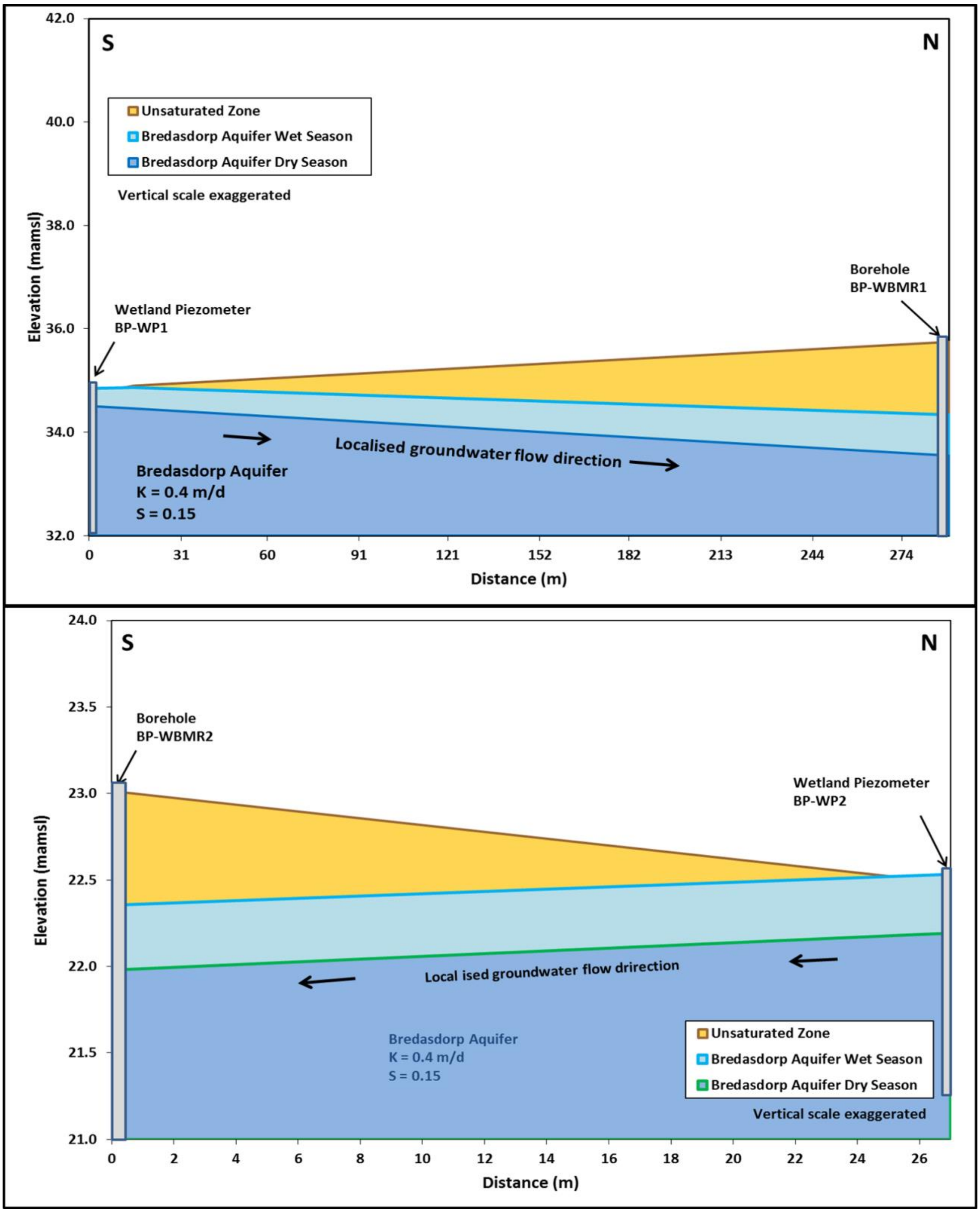
The Koks River flows off the north eastern portion of the site above the R43, and its catchment within the study area includes broad hillside seepage wetlands, occasional seasonally inundated springs or pans and, along the river channel itself, a dense band of *Prionium serratum* (Palmiet) vegetation. The river on the site is believed to be relatively unimpacted and of high conservation importance. The importance of the Ratels River wetlands downstream as a habitat for two red-data frog species has also been noted (Day 2005).

The interaction between the groundwater and the wetlands can be summarised as follows:

- the wetlands are fed by the Haelkraal River and lose water to the deeper groundwater table of the Bredasdorp Aquifer(**Figure 2.40**);

- chemical and isotopic data show that there is not much difference between the wetland water and groundwater, thereby supporting the interaction described in bullet point one; and
- this is further supported by the similarity in water level behaviour of the wetland and the groundwater in relation to dry and wet seasons, as well as rainfall events.

Figure 2.40: Cross-section Showing Wet and Dry Season Water Levels in the Haelkraal River Wetland Piezometers and Nearby Boreholes



No wetlands were identified within the EIA Corridor area.

The natural wetlands identified in the study area would be sensitive to any activities that resulted in their physical disturbance, drainage, infilling or changes to their natural hydrological regime, including both surface and subsurface and / or groundwater flow linkages, and changes in water quality – particularly, nutrient enrichment (Day, 2005). The wetlands are also sensitive to any activities that would increase their vulnerability to invasion by alien plants. Important processes that would need to be maintained are likely to include hydrological connectivity and the maintenance of riverine and wetland corridors, between source areas and the sea.

2.2.15 Aquifer Classification and Vulnerability

The whole area between the coast and the inland plains of the Overberg is classed as a Major Aquifer according to a WRC project report and maps (Parsons and Conrad, 1998). However, it is stressed in this report that this is a regional classification only and cannot be used on a site-specific basis. The area around Pearly Beach is further classified as a Sole Source Aquifer (Parsons and Conrad 1998). Such an aquifer is defined as "*an aquifer which is used to supply 50 per cent or more of domestic water for a given area and for which there are no reasonably available sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial"*.

The latter qualification, particularly with respect to yield, is important to bear in mind, as the 'Sole Source' classification of the local aquifer gives the impression of the existence of a special aquifer, possibly with good yield and quality characteristics. However, it merely reflects the fact that there is no viable alternative supply. Towns such as Pearly Beach where this situation exists have merely been listed by DWA. There is no map showing the boundaries of such aquifers. The hydrocensus and drilling results indicate that boreholes drilled into the TMG, Granite and Bredasdorp aquifers located beneath Bantamsklip and its immediate surrounds are all low yielding, which suggests a minor aquifer. The only proven aquifer in the study area seems to be the high-lying range of calcified sand dunes stretching from the northern part of Bantamsklip in a north-westerly direction towards the road between Pearly Beach and Baardskeerdersbos. These deposits belong to the Bredasdorp Group.

Groundwater potential at the site is low and geohydrological considerations should not be an issue in the siting of a NPS. Only small quantities of groundwater should be expected in excavations on site. The Sole Source Aquifer classification does not apply to the site because Pearly Beach's groundwater supply is located *c*.6 km to the north, and up-gradient of the site. The areas beneath and immediately surrounding the site can be classified as being a Minor Aquifer System in terms of the national classification criteria. This aquifer class has low borehole yields, produces groundwater with variable quality and is of limited significance and has a moderate to low vulnerability to anthropogenic impacts (Parson and Conrad, 1998). This also implies that groundwater is not a viable resource for water supply during the operational or construction phases.

2.2.16 Conceptual Model

The conceptual model for the site is based on existing information and data and information derived from the EIA phase (**Figure 2.41** and **Figure 2.42**). Key features include:

- The relatively flat topography which slopes gently towards the coast. The topography rises to the north-east to highs of between 150 and 200 mamsl.

The coastal strip reveals a wave-cut platform developed on the bedrock, which is only exposed in a narrow rocky belt from the high-tide mark. The coastal belt becomes sandier to the south-east with less rock exposure;

- Although no river channels drain the immediate site, the broader area is drained by the perennial Haelkraal, Koks, Wolfgat and Ratel rivers which flow in a south-eastward direction towards the coast;
- The bedrock at the site consists of the Cape Granite Suite (Granite Aquifer) and TMG sandstone (TMG Aquifer) which can be broadly classified as secondary or fractured-rock type aquifers. These rocks are covered by superficial deposits and so any aquifers developed are likely to be semi-confined;
- The superficial deposits of the Bredasdorp Group (Bredasdorp Aquifer) are classified as primary or an intergranular aquifer. The upper boundary of the aquifer is the water table and this aquifer is therefore unconfined;
- Shallow groundwater levels are the result of the groundwater on site being at the end of its flow path with the site being very close to the coastline, i.e. located in a groundwater discharge zone. The influence of tides may influence temporal variations in groundwater levels;
- The water table generally mimics the topography with flow being in a south-westerly direction towards the ocean and becoming more southerly closer to the Haelkraal River.

In addition, the following specific characteristics and geohydrological conditions apply:

- Groundwater flow velocities in the Bredasdorp Aquifer range from *c*.0.7 m/d in the higher lying area in north-east to *c*.0.2 m/d in the flat lying central area, to *c*.1 to *c*.1.7 m/d at the reactor footprint and towards the coast;
- Average groundwater flow velocities in the TMG Aquifer range from 0.01 m/d in the flat lying central area, to 0.04 m/d at the reactor footprint to 0.1 m/d at the coast.
- Groundwater flow velocities in the Granite Aquifer change from 0.001 m/d in the flat lying areas to 0.002 m/d in the higher lying areas;
- Due to the unconfined nature of the primary aquifer, recharge takes place over the entire area. A recharge estimate of *c*.15 per cent is considered reasonable given the genarlly sandy nature of the soils;
- The Bredasdorp Aquifer is classed as having median borehole yields of 0.5 to 2.0 L/s;
- Generally low yielding boreholes with long term yields ranging between 0.05 and 1 L/s with a median of 0.25 L/s are encountered in the TMG Aquifer. Maximum pump yields achieved during step drawdown tests range from 0.12 to 3.12 L/s with a median yield of 0.91 L/s;
- Low yielding boreholes were encountered in the Granite Aquifer with maximum yields ranging between 0.11 and 0.30 L/s with a median of 0.20 L/s, which are very low. Sustainable yields are even lower and estimated to be 0.07 L/s or less.

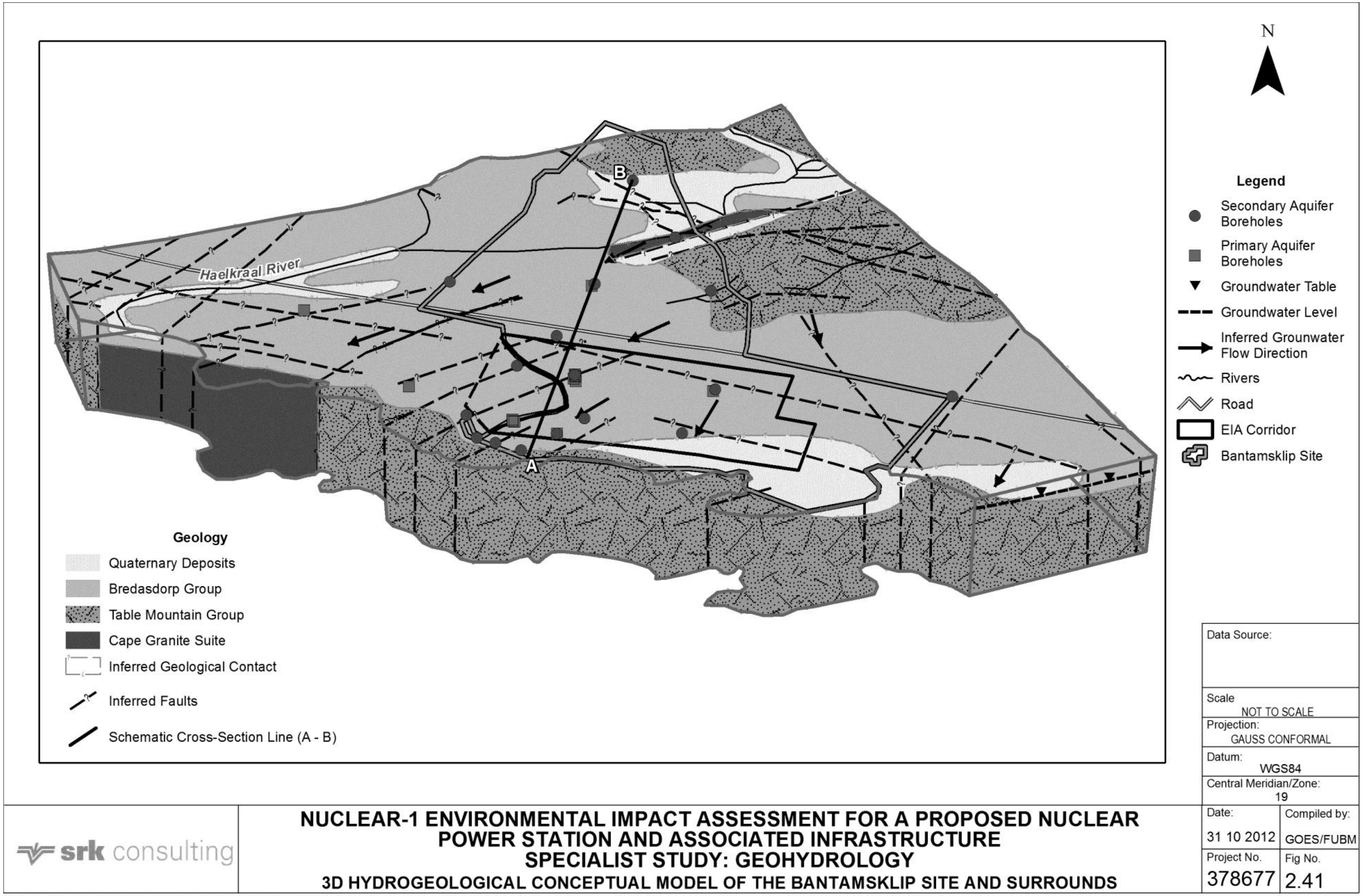


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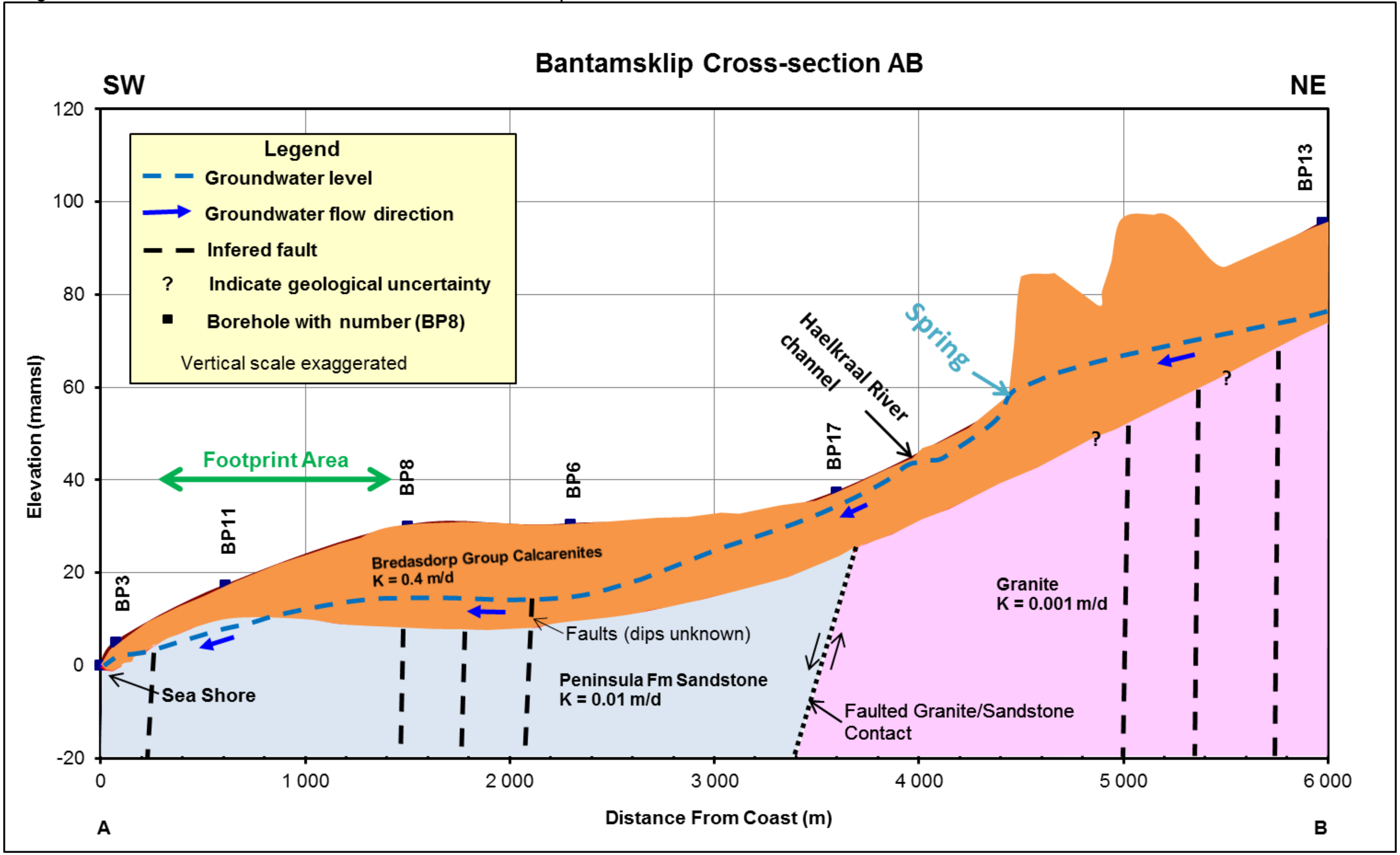
Figure 2.42: Schematic Cross-Section for the Bantamsklip Site



2.2.17 Numerical Modelling

a) REGIONAL MODEL

The regional model covered the whole of quaternary catchment G50A (**Figure 2.43**). The network constructed for the area consists of 280 x 195 cells in the x and y directions, respectively. Each of the cells is 100 x 100 m. The coordinates for the modelled area are:

- Lower left corner 40 800, -3 850 800;
- Upper right corner 68 800, -3 831 300.

The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulated results.

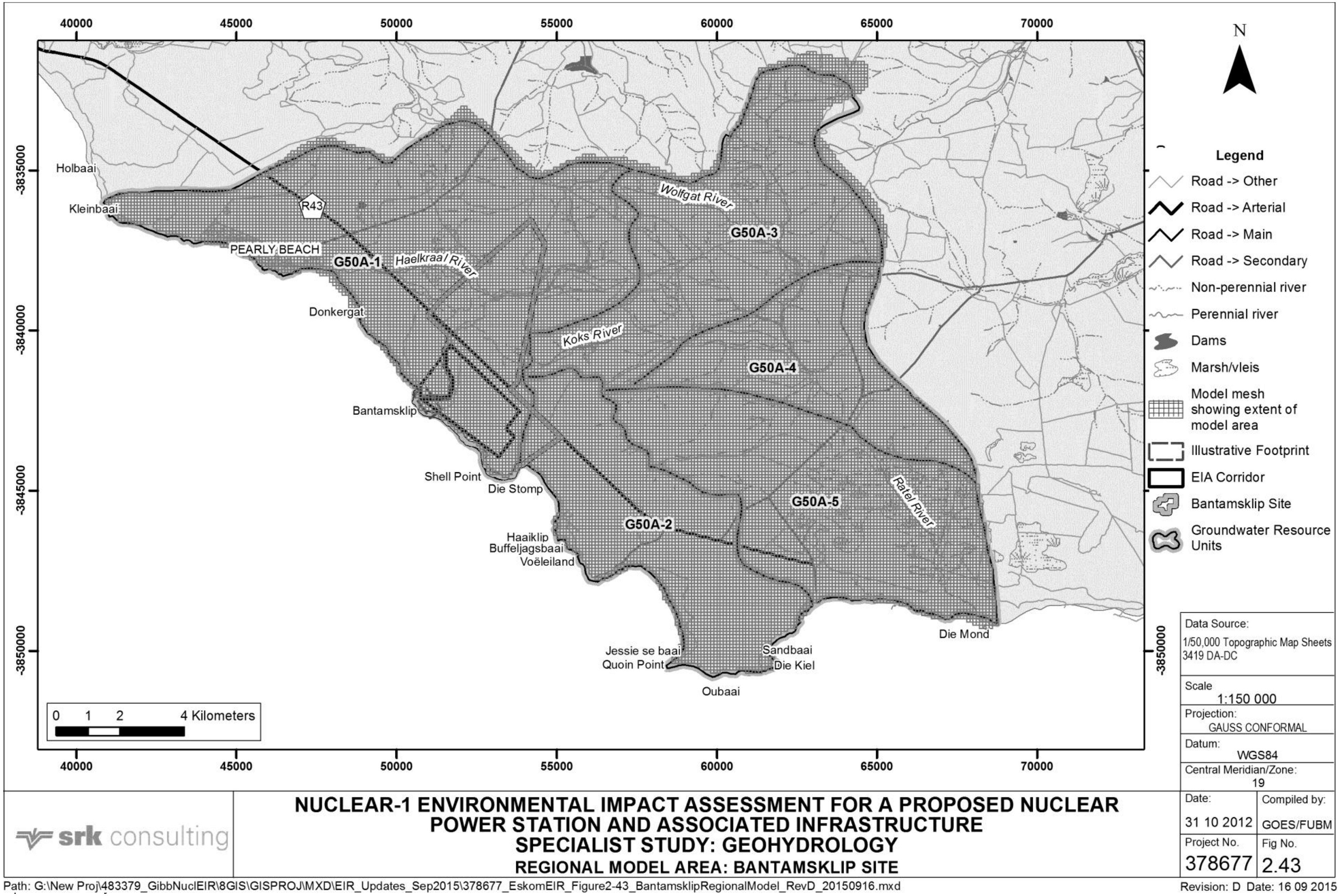
Modelling Software and Solver - *MODFLOW88/96* (Harbaugh and McDonald, 1996) a modular three-dimensional finite difference groundwater flow model which was developed by the U.S. Geological Survey, was the software used during this investigation. It is an internationally accepted and benchmarked modelling package that calculates the solution of the groundwater flow equation using the finite difference approach. The Preconditioned Conjugate-Gradient Solver Package (*PCG2*) is is used to solve the finite difference equations in each step of the *MODFLOW* stress periods.

Boundary conditions - The Atlantic Ocean was set as a constant head of 0 mamsl. The Ratel River was also set as a constant head. All other boundaries were set as no flow boundaries.
In addition to the boundary conditions the wetlands in the area were simulated as drains.

Initial conditions - In order to set up a groundwater flow model for the area, a water level contour map must first be generated (see previous section). Water levels so generated were used as initial water levels.

Sources and sinks - Sources and sinks can be defined as recharge and abstraction sources in the aquifer, respectively. Sources can be precipitation and inflow from surface water and recharging boreholes. Sinks can be abstraction boreholes, mines, springs, evapo-transpiration and outflow to surface water. The initial groundwater recharge values used in the model are 5 per cent of mean annual precipitation.

Aquifer parameters - Analysis of the pumping test data indicates leaky aquifer conditions in the bedrock at most of the boreholes, indicating leakage from the overlying Bredasdorp Aquifer into the TMG Aquifer during abstraction. Transmissivity values were calculated to range from <1 to 6 m^2/day with a median value of *c*.4 m^2/day. Similarly, S was calculated to range from $1.1x10^{-3}$ to $6x10^{-3}$ with a median of $1.9x10^{-3}$ and K ranging from 0.01 to 0.17 m/day with a median of 0.03 m/day.



40000
45000
50000
55000
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65000
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-3835000
-3840000
-3845000
-3850000
Holbaai
Kleinbaai
R43
PEARLY BEACH
G50A-1
Haelkraal River
Donkergat
Wolfgat River
G50A-3
Koks River
G50A-4
Bantamsklip
Shell Point
Die Stomp
G50A-2
G50A-5
Ratel River
Haaiklip
Buffeljagsbaai
Voëleiland
Jessie se baai
Quoin Point
Sandbaai
Die Kiel
Oubaai
Die Mond
0 1 2 4 Kilometers
N
Legend
Road -> Other
Road -> Arterial
Road -> Main
Road -> Secondary
Non-perennial river
Perennial river
Dams
Marsh/vleis
Model mesh showing extent of model area
Illustrative Footprint
EIA Corridor
Bantamsklip Site
Groundwater Resource Units
Data Source:
1/50,000 Topographic Map Sheets 3419 DA-DC
Scale
1:150 000
Projection:
GAUSS CONFORMAL
Datum:
WGS84
Central Meridian/Zone:
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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
REGIONAL MODEL AREA: BANTAMSKLIP SITE
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The T values obtained from pumping tests conducted during this study are listed in **Table 2.23**.

The transmissivities of the Granite Aquifer are <1 m^2/day.

Table 2.23: Transmissivity Values for Bantamsklip Boreholes

Borehole	Transmissivity (m^2/d)
BP19	5
BP26	4
BP27	<1
BP28	5
BP1	<1
BP2	2
BP3	1
BP4	1
BP5	3
BP6	2
BP7	4
BP8	4
BP10	<1
BP16	<1
BP17	<1
BP20	4
BP21	<1
BP24	6

Transmissivity in an aquifer such as the TMG fractured aquifer varies naturally and it is not possible or necessarily desirable to get consistent values. Variable T values are therefore a function of aquifer anisotropy and heterogeneity and not related to any flaw in investigative or analytical methods.

<u>Steady state calibration</u> - The steady state head distribution is dependent upon recharge, transmissivity, 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 T value. The simulated head distribution can then be compared to the measured head distribution and the transmissivity or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained. An advantage of a steady state model is that the parameter for S is not required to solve the groundwater flow equation - therefore there are less unknown parameters to determine. The calibration process was done by changing the model parameters for T and recharge within realistic values. Seventeen boreholes were used to calibrate the steady state groundwater flow model. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads (**Figure 2.44** and **Figure 2.45**). A square of the Pearson product moment correlation coefficient of 0.92 was achieved, which meets the model calibration criteria of minimum 0.80.

The model calibrated best with a T of 3 m^2/d. Transmissivity of the geological lineaments/faults was set at 50 m^2/d. The average recharge for the area was set at 5 per cent of the mean annual precipitation.

The model mass water balance is shown in Table 2.26. As can be seen, the mass balance percent error is *c*.0.0005 per cent which is within the calibration criteria requirement of <0.5 per cent.

Table 2.24: Bantamsklip Regional Steady State Mass Water Balance

	Inflow (m^3/d)	**Outflow (m^3/d)**
Recharge	9 528	0
Sea (Constant Head)	0	3 151
Rivers	172	4 075
Groundwater Inflow to Wetlands	0	2 475
Pumping Boreholes	0	0
TOTAL	**9 701**	**9 701**
Mass Balance Percent Error	**0.0005%**	

It is important to note that as this was a regional model, a geometric mean value for the transmissivities in the Granite and TMG aquifers were determined and set for the entire area. Blow-yield data and yield data recorded during the hydrocensus were included in this analysis.

In the local model (which includes more detail) discussed in a later section of this report, the above-mentioned values can differ and also differ from some of the test pumping derived T values. However, the modelling is considered to provide a better indication of more regionally applicable T values for predictive purposes.

Figure 2.44: Simulated versus Observed Data Sets, Bantamsklip Regional Model

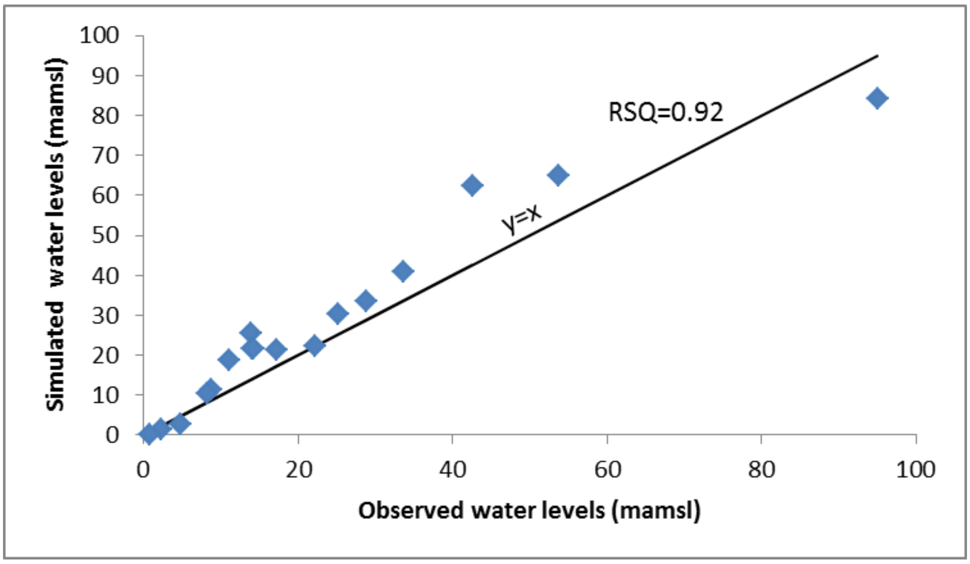
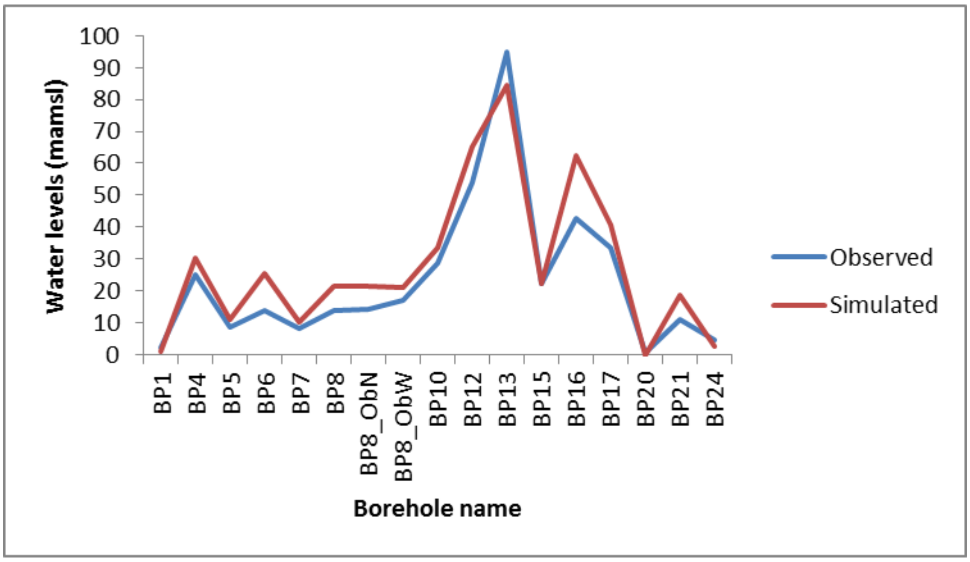


Figure 2.45: Simulated versus Observed Water Levels, Bantamsklip Regional Model



<u>Numerical mass transport model</u> -

Input concentrations of contaminants

Input concentrations in the model were specified at cells over the areas where contamination is expected e.g. across the areas where air dispersions are going to be high, and footprint area.

Transmissivities

Transmissivities for the aquifer were specified according to the values obtained during the scenario of the steady state water level calibration (see **Subsection 3.6.1**).

Porosity values

One of the biggest uncertainties encountered during transport modelling of pollutants is the kinematic porosity of the aquifer. A value of 10 per cent was assigned to the modelled area.

Longitudinal and transversal dispersivities

A longitudinal dispersivity value of 100 m was selected for the simulations (see Table D.3 – Field-Scale Dispersivities in Spitz and Moreno, 1996). Bear and Verruijt (1992) estimate the average transverse dispersivity to be 10 to 20 times smaller than the longitudinal dispersivity. An average value of 10 m was selected for this parameter for the simulations.

Hydraulic heads

The hydraulic head values as calculated during the steady simulations were specified in the model.

<u>Scenario using regional model: Potential groundwater contamination due to air pollution from site</u> -

Scenario 1: Deposition of tritium

In this scenario the movement of ^3H is simulated from the deposition thereof on the ground, to the movement of it in the groundwater system. Tritium is modelled as though it is conservative, i.e. it is not affected by attenuation processes such as adsorption and precipitation. It is once again important to note that the nature of the subsurface (vegetation and soil types present) will also play a role in movement. Therefore, this scenario can only serve as an indication of what can occur and must be seen as qualitative and not quantitative. Using average annual emissions assuming EPR and AP1000 units to make up the 4 000 MWe and most of the wetlands and boreholes could be affected by emissions, although the concentrations will be low, i.e. *c*.2.5 TU. This is for a 20- year indicative simulation period; 2.5 TUs are equivalent to 0.3 Bq/L. The WHO's limit for drinking water is 10 000 Bq/L.

b) LOCAL MODEL

Generation of finite difference network - For the local model the southwestern boundary was set as the Atlantic Ocean, the north-western and south-eastern boundaries were set as fault lines (**Figure 2.46**). The northern boundary was set as the quaternary catchment boundary and the eastern boundary was set as the Ratel River. The model consisted of 330 x 400 cells in the x and y directions, respectively. Each of the cells is 50 x 50 m. The coordinates for the modelled area are:

- Lower left corner 44 000, -3 850 000
- Upper right corner 64 000, -3 833 500

In order to include more detail in the model two layers were included, namely:

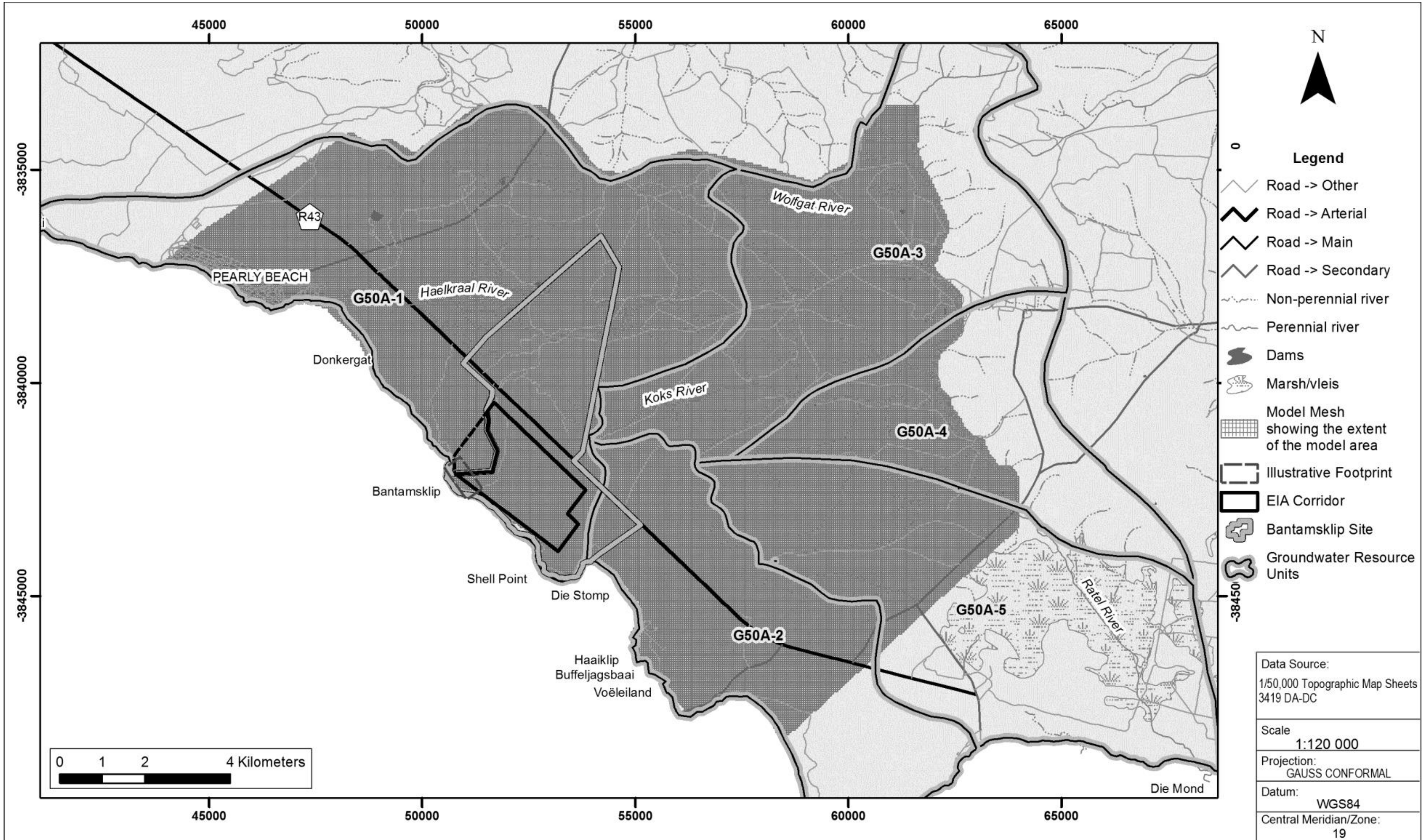
- Layer 1: Intergranular primary aquifer
- Layer 2: Fractured secondary aquifer

The local model was recalibrated in 2010 by using the wetlands and SSR monitoring data. Subsequent re-simulation of the scenarios did not show any material changes from the original results obtained.

Boundary conditions -The south-western boundary of the site is initially set as a constant head boundary of 0 mamsl to represent the sea. 'Sea constant heads' were inserted in both model layers (representing the thin intergranular primary and fractured secondary aquifer) at the coastline itself as there is no conceptual reason or indication of fresh water aquifer flow at depth extending out below the sea (such as a confining layer/aquitard would provide).

All other boundaries were set as no flow boundaries, except for the Ratel River which was also set as a constant head.

Initial conditions - The initial water levels were once again used as initial conditions in this model. It is important to note that the first layer is dry in some areas due to there only being a water level in the deeper secondary aquifer system.



Data Source: 1/50,000 Topographic Map Sheets 3419 DA-DC

Scale: 1:120 000

Projection: GAUSS CONFORMAL

Datum: WGS84

Central Meridian/Zone: 19

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
LOCAL MODEL AREA: BANTAMSKLIP SITE

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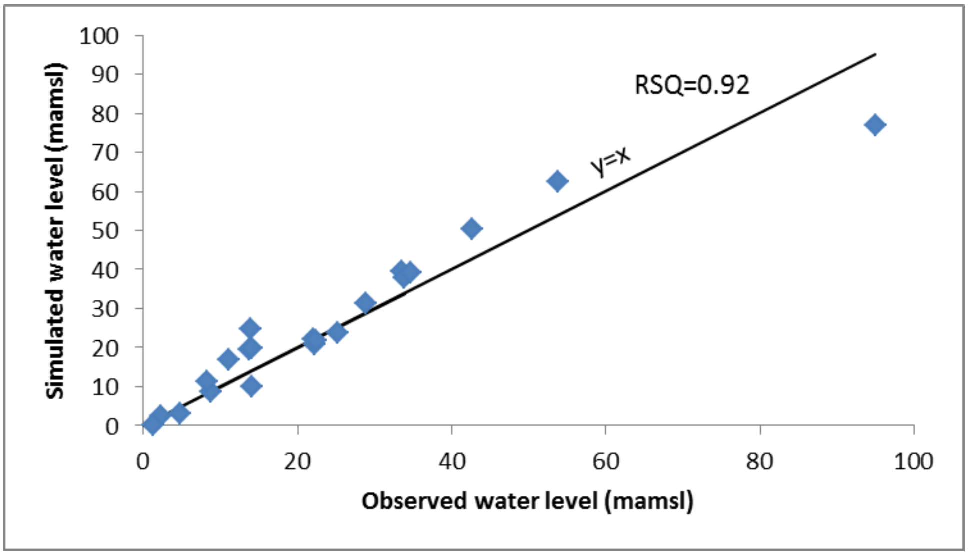
Sources and sinks - The initial groundwater recharge values used are those documented in **Subsection 2.2.5**. The wetlands were set as drains with the drain depth equal to topography.

Aquifer parameters - A transmissivity of 5 m^2/d and storativity of 1.5 x 10^{-1} (dimensionless) were assigned to layer 1. A transmissivity of 4 m^2/d and a storativity 1.9x10^{-3} were assigned to layer 2, for calibration of the steady state flow model.

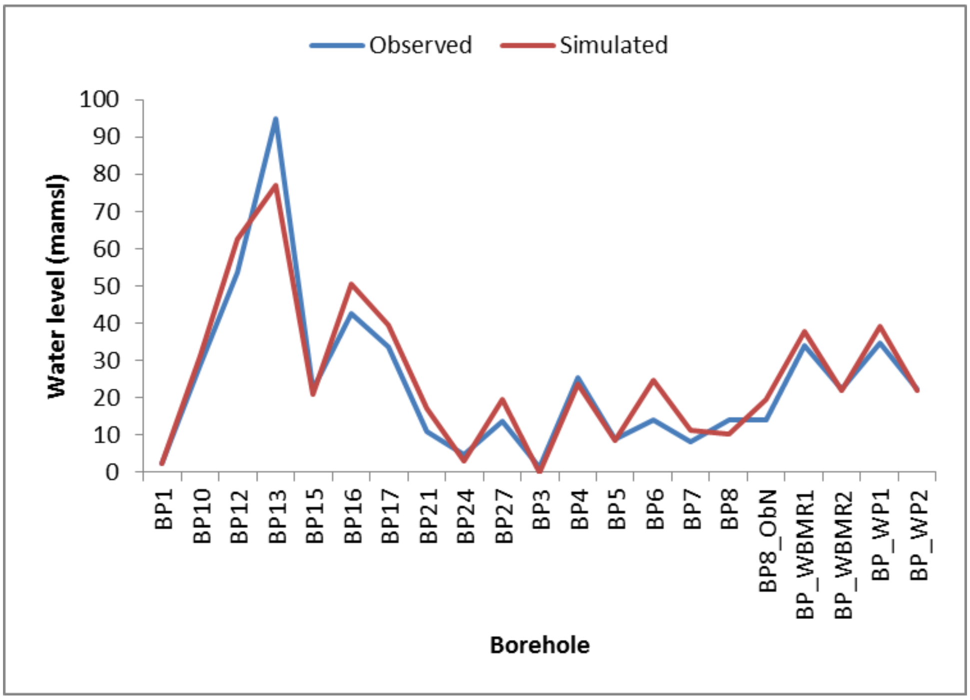
The results of the steady state simulation are shown in
Figure 2.47 and **Figure 2.48**.

Figure 2.47: Simulated versus Observed Data, Bantamsklip Local Model



Scenarios using local model - Once the model was calibrated predictive scenarios were run to assess the impacts of various activities on site on the groundwater system. These activities include dewatering and the movement of potential contamination.

Figure 2.48: Simulated versus Observed Water Levels, Bantamsklip Local Model



Scenario 1: Dewatering a hypothetical "footprint"

In this scenario an entire representative footprint is dewatered to simulate excavation to the foundations for the NPS. Simulation of foundation excavations is assigned to 10 mbgl, as the bedrock is locally within 10 m of the surface. The zone of depression is neglibible. The expected inflows into the foundation excavation are 30 m^3/d, as documented in the model scenario water balance table (Table 2.25).

Table 2.25: Scenario 1 Water Balance, Bantamsklip Site (Dewatering to 10 mbgl)

	Inflow (m^3/d)	**Outflow (m^3/d)**
Recharge	15	0
Sea (Constant Head)	0	50
Inflow to Foundation Excavations (Drain)	**0**	**30**
Flows between TMG Aquifer Below	14	7
Flows on Northern Boundary	0	11
Flows on Southern Boundary	43	0
Flows on Western Boundary	0	35
Flows on Eastern Boundary	61	0
TOTAL	**133**	**133**

In this case the maximum drop in groundwater level in the vicinity of the wetlands is <1 m. The zone of depression is mostly contained to the site. This is a worst case scenario that is unlikely to occur.

Scenario 2: Dewatering a third of the footprint

In this scenario only a third of a hypothetical footprint is dewatered which corresponds to a Nuclear-1 size NPS installation. The expected inflows are 20 m^3/d, as documented in the model scenario water balance table (Table 2.26).

Table 2.26: Scenario 2 Water Balance, Bantamsklip Site (Dewatering to 10 mbgl)

	Inflow (m^3/d)	Outflow (m^3/d)
Recharge	15	0
Sea (Constant Head)	0	53
Inflow to Foundation Excavations (Drain)	**0**	**20**
Flows between TMG Aquifer Below	11	8
Flows on Northern Boundary	0	12
Flows on Southern Boundary	42	0
Flows on Western Boundary	0	35
Flows on Eastern Boundary	60	0
TOTAL	**128**	**128**

The zone of depression is limited to the site and no wetlands are affected.

A 95 per cent impermeable cut-off barrier was inserted in the two layers of the model surrounding the footprint. The length of the barrier is correctly defined by the site boundary, however the modelled width of the barrier is 50 m, as defined by the model cell size. This will not have a major impact on flow directions and modelled drawdowns, however, as the barrier will still act as a flow impeder in the same orientation. By including the cut-off wall the maximum inflow is reduced to 7 m^3/d, the zone of depression is significantly smaller and no wetlands are impacted. This is the most likely scenario.

There will be an impact on groundwater equilibrium when dewatering/ groundwater control measures are implemented for excavation of the foundations for the NPS. These control measures could include cut-off walls and pumping boreholes/wells. They will result in local drawdown of the water table in the short-term but equilibrium will be restored outside of the NPS footprint area with time. Managed artificial recharge could be employed to assist with restoring the *status quo*, with pumped groundwater being fed back into the aquifer. However, the upper Bredasdorp Aquifer is poorly developed at the site and disruption of groundwater equilibrium will be minimal.

Scenario 3: Impact of increase in seawater level on groundwater system

The sea level is raised by 1.2 m in this scenario, based on predictions contained in the Intergovernmental Panel on Climate Change (*op cit*). The resultant increase in groundwater levels are shown in
Figure 2.49. The increase in groundwater levels is a maximum of *c*.1.2 m at the coast decreasing to 0.2 m at the inland extremity of the illustrative footprint. This increase is relatively insignificant in terms of the site safety issues and can easily be taken account of in any groundwater control/management system. These simulations will be updated as necessary with any increases in predicted rise in sea level due to global warming but should likewise be controllable within the groundwater management system designed.

Scenario 4: Impact of increase in seawater level on dewatering

This scenario is a repeat of scenario 1, but with sea level raised by 1.2 m. The expected inflow for excavation foundations to 10 mbgl is 38 m^3/d. However, dewatering is likely to take place long before significant sea level rise impacts are manifested if the site is approved for installation of an NPS.

In this case the maximum drop in groundwater level in the vicinity of the wetlands is <1 m. The zone of depression is contained to the site.

Scenario 5: Groundwater as a potential source of water

Abstraction scenarios have not been simulated because indications from the groundwater investigation is that groundwater is not a viable supply source to a NPS and it is unlikely that a wellfield could be developed for any other user in the site area.

Scenario 6: Potential contamination of the site

In this scenario the potential contamination from the site is simulated. It is assumed that the entire hypothetical footprint is 100 per cent contaminated (specific contamination type unspecified at this stage but non-radioactive). The contamination plume after 50 years is shown in
Figure 2.50. Most of the contamination moves towards the ocean with time. However, there is a zone of approximately 200 m around the footprint that could become contaminated. The area potentially impacted would not be larger for radioactive contaminants. Contamination movement within fractures could be different but this is unlikely to be significant given that there is no pumping from the fractured aquifer and there is unlikely to be any in the future. Assuming that an impermeable cut-off wall is installed around the reactor area, this will help contain any liquid contaminants emanating from this source.

Scenario 7: Potential for seawater intrusion

In this scenario the potential of seawater intrusion into the site aquifers is investigated under the influence of dewatering for foundations in the footprint area. As *PMWIN* is not ideal for simulating seawater intrusion, it can only provide a qualitative indication of the possibility of such intrusion. *PMPATH* is included in the *PMWIN* package. This add-on package simulates the advective transport of particles within an aquifer system. Particles were introduced at the coastline and tracked with time. The results indicate that seawater intrusion could occur to a radius of 380 m along the coastline in the vicinity of the footprint, depending on set-back distance from the coast. Isolated flows could occur along fracture zones.

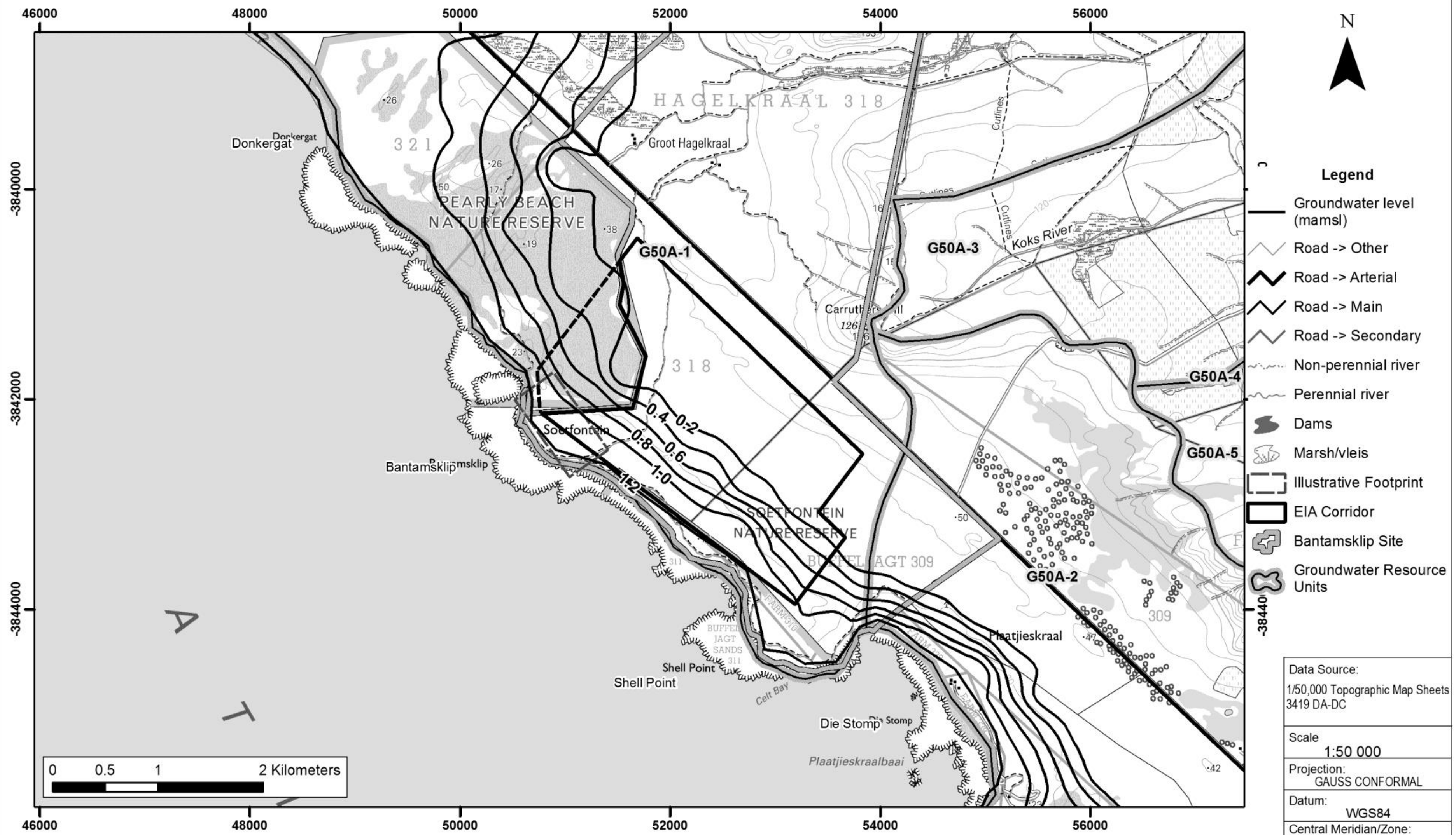
c) CONCLUSIONS

The results of the numerical modelling indicate that zone of dewatering due to foundation excavations would be a maximum of 2.75 km when dewatering an entire footprint (unlikely) and 1.5 km (more likely) when dewatering only a third of the footprint. This zone intercepts some wetlands within the vicinity of the EIA Corridor. However, as these wetlands are fed by the Haelkraal River and drain to the deeper groundwater table, lowering of the water table will not impact on the wetlands or the river.

An increase in seawater levels will lead to an increase in groundwater levels along the coastline. However, although increases are expected across the entire footprint area, they are relatively small and can be accommodated in any groundwater management system.

All potential NPS liquid emissions entering the groundwater system would migrate towards the sea and as such very little groundwater contamination is expected. However, the cut-off wall will help to contain any such emissions. Gaseous emissions would be dispersed by the prevailing winds but would be at low concentrations from normal operations.

Seawater intrusion is likely in the vicinity of the NPS footprint under dewatering conditions, depending on set-back distance from the coast.



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Project No. 378677	Fig No. 2.49

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
SCENARIO 3: INCREASE IN GROUNDWATER LEVELS DUE TO INCREASE IN SEA WATER LEVEL, BANTAMSKLIP SITE

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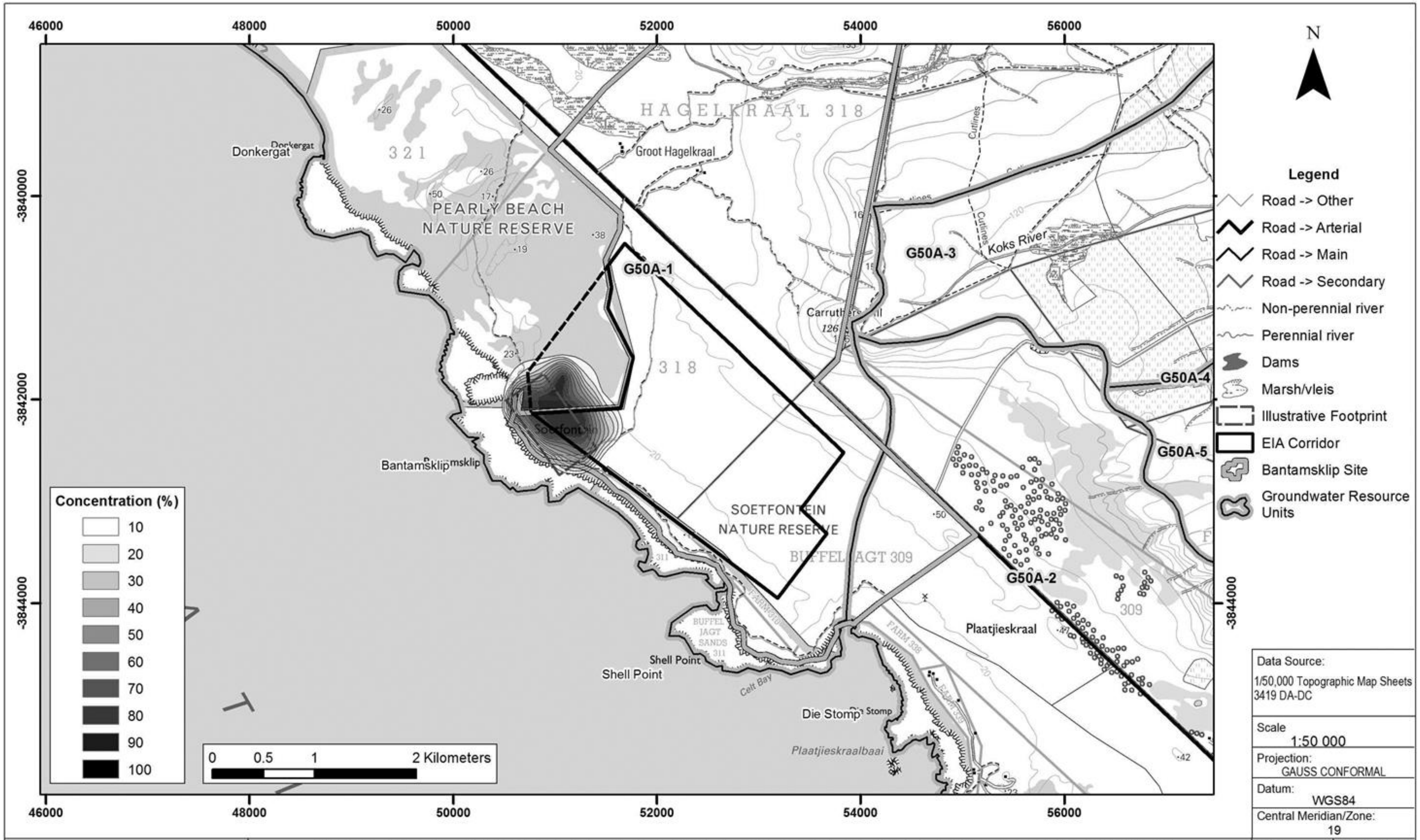

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Project No.	Fig No.
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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
NUCLEAR CONTAMINATION AFTER 50 YEARS: BANTAMSKLIP SITE

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2.3 Thyspunt

2.3.1 Extent and Physiographic Setting

The area surrounding the Thyspunt site is dominated by unvegetated dunes, non-perennial pans, shrub and bush to the north with the ocean and TMG outcrop along the coastline. The topography rises from sea level at Thysbaai to 80 to 100 m past the dune fields (**Figure 2.51**). The topography rises to 150 to 180 m above sea level towards the Krom River to the north and west and flattens out to 100 to 120 m around Humansdorp before rising to >200 m further north and west. Towards the east the topography rises to around 100 m above sea level with a gentle slope down towards the ocean. Aeolian sand dunes occur to the east between Thyspunt, Sea Vista and Cape St. Francis and towards the west to beyond Oyster Bay.

The climate at the site and in the study area is classified as warm temperate. Temperatures are mild and the lowest and highest mean absolute maxima at nearby Cape St. Francis are 5.0 °C and 29.8 °C, respectively. Extremely high temperatures (up to 35 °C) are occasionally experienced during berg wind conditions in spring and autumn, and berg winds are most common in winter. The climatic regime is dominated by alternating successions of eastward moving cyclones and high pressure anti-cyclones. Westerly winds occur with the passage of low pressure cyclones and are most frequent in winter months and associated with cloudy weather and rain. Heavy rainfall often occurs with post-frontal southerly winds and with cut-off low conditions, which are most common in spring (September and October) and autumn (March and April). The area experiences strong winds and gales at any time of the year, though late spring and summer are usually the windiest periods. The prevailing wind direction is south-westerly to north-easterly.

Rainfall figures from the nearby St. Francis Bay weather station indicate an average of 60 mm of rainfall per month with the wettest months being winter (July to August, 85 to 95 mm/month) and the driest months being summer (December to February, 35 to 55 mm/month). Mean annual precipitation as measured at Humansdorp, which has the longest record in the site area, is 687 mm.

The area surrounding the site comprises four quaternary catchments: K80F, K90D, K90E and K90F.

The prominent drainage in the area is the Krom River which flows from the north-west of Thyspunt to an estuary and drainage into the ocean north of Sea View. The Krom River occurs at a distance greater than 7 km from the site, and the Impofu Dam is located along this river. This dam is one of seven sources of water for the Nelson Mandela Bay Municipality. Other perennial rivers occurring in the area are the Slang River which flows into the ocean at Oyster Bay, the Klipdrift River, with the associated small Klipdrift River Dam, which flows into the ocean west of Oyster Bay, the Geelhoutboom River (a tributary of the Krom River) and the Seekoei River, which flows into the ocean via an estuary at Aston Bay. These rivers follow the northwest-southeast striking geological formations (Bokkeveld and TMG rocks), which dominate the area. Small non-perennial rivers occur throughout the area and dry and non-perennial pans occur among the younger Quaternary-age dunes, which lie along the coast from west of Oyster Bay to north-east of St. Francis Bay.

The site and site area are also characterised by the presence of a series of wetland systems. Those occurring on the Thyspunt site (see **Figure 2.51**) and of significance to this study comprise, from north to south across the site:

- Wetland depressions/duneslack wetlands;
- Hillslope seeps;
- Coastal seeps.

The first wetland type is seasonal in nature and forms during the rainy season as the shallow water table rises to fill depressions in the dunefields. The second forms the prominent Langefonteinvlei wetland occurring in the eastern part of the site. The third occurs intermittently along the coast with varying flow rates.

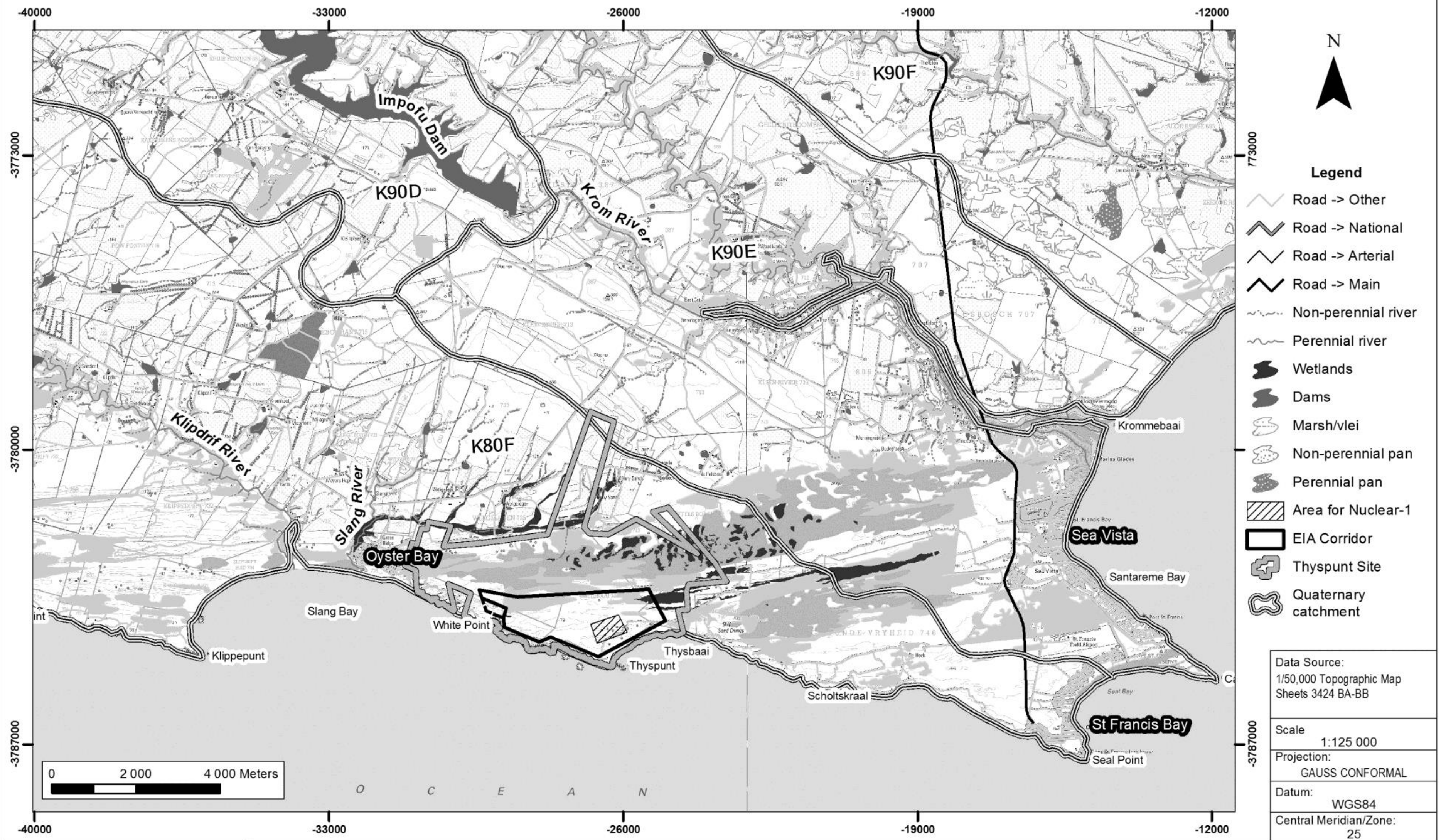
2.3.2 Regional Groundwater Occurrence

The groundwater regime surrounding the site is detailed in the DWAF 1:500 000 Hydrogeological map series, sheet 3324, Port Elizabeth (Meyer *et al.,* 1998). The details on the DWAF map have subsequently been confirmed and more detail added with the geohydrological (and to a lesser extent, geotechnical) drilling programmes.

The superficial deposits of the Algoa Group are classified as a primary or intergranular aquifer. Groundwater flow and storage takes place within the original pore spaces between constituent grains. The upper boundary of the aquifer is the water table and this aquifer is therefore unconfined. For the purpose of this study the primary aquifer is called the Algoa Aquifer.

The following regional information pertains to the intergranular aquifer within the Nanaga and Alexandria formations (Algoa Group):

- Groundwater mainly occurs in the basal Alexandria conglomerate which shows variable thickness and is discontinuous; The Nanaga aeolianite dominates the Algoa sediments in the Thyspunt site area but the Alexandria conglomerate has been identified as underlying the aeolianite across the eastern and southern parts of the site;
- Water seeps rapidly through the highly porous, fine sandy and calcareous material to the base of the intergranular aquifer, where rapid flow occurs in the basal conglomerate and along the contact with the underlying TMG rocks. The groundwater flows out as seeps or commonly occurring springs at sea-level and from within the dune fields;
- Build-up of groundwater seldom occurs because of the high hydraulic conductivity of these formations;
- Groundwater flow direction is to the south / east with discharge along the beaches and rocky outcrop into the ocean, and to the south-east into the adjacent Sand River Aquifer system. Local groundwater flow also occurs in westerly and eastern directions, possibly along channels between the dunes and then with subsequent southerly flow towards the ocean. Note: Based on the groundwater level contours, groundwater at the site does not flow into the Sand River Aquifer system;



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Project No. 378677	Fig No. 2.51

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY

LOCALITY MAP FOR THE THYSPUNT SITE

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- Borehole yields from the Algoa Aquifer are typically <0.5 L/s and groundwater levels at 10 to 20 mamsl. However, yields from the basal conglomerate can be in the order of 10 to 15 L/s;
- A high yielding significant intergranular aquifer occurs to the east of Thyspunt at Mostert's Hoek and St. Francis Bay, where a spring with a yield of 8 L/s occurs.

Due to the rapid flow of groundwater through the Algoa Group sediments, the proximity to the coast and relative impermeability of the fractured rock aquifer, limited interconnection between the intergranular aquifer and fractured rock aquifer is envisioned in the Thyspunt site area.

The following regional information pertains to the fractured rock aquifer, mainly within the TMG rocks (Meyer *et al.,* 1998 and Vegter,1995). The Bokkeveld rocks can be classed as an aquiclude in the general site area:

- A network of joints and fractures control the infiltration, recharge, storage and movement of groundwater in the competent but often brittle TMG, with deep fracture extensions providing deep groundwater circulation (Vegter, 1995);
- A network of joints and fractures control the infiltration, recharge, storage and movement of groundwater in the competent but often brittle TMG, with deep fracture extensions providing deep groundwater circulation;
- The average depth to groundwater within the fractured rock aquifer is *c*.30 to 50 m below ground surface;
- Average sustainable borehole yields range from 0.5 to 2 L/s, but yields of >5 L/s have been obtained from discrete fractures;
- Springs are common in the TMG and are fault or lithologically controlled by impeding layers such as the Cedarberg Formation shale;
- Recharge to the fractured rock aquifer occurs in relatively high rainfall areas located at high elevations and an average of *c*.15 per cent infiltration of precipitation occurs, but higher recharge rates are possible;
- The fractured rock aquifers are classified as minor aquifers of moderate vulnerability;
- Groundwater flow directions are predominantly to the south and east with flow from higher elevation discharging into the ocean;
- Groundwater flow from higher elevations around the Krom River occurs towards the river, then south-east towards the ocean.

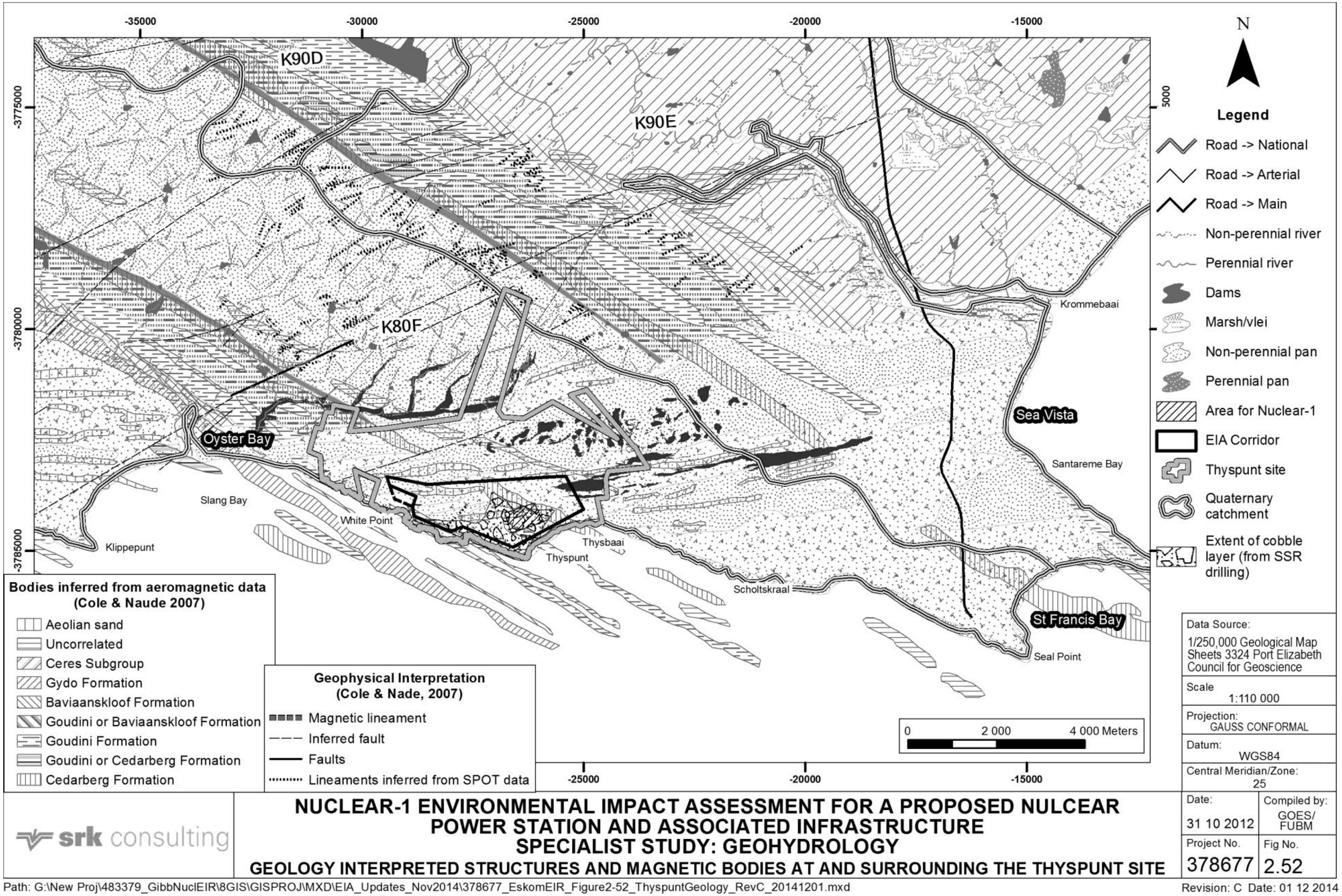
2.3.3 Lithostratigraphy

Algoa Aquifer

The detailed geohydrological study at the site has revealed evidence that the intergranular aquifer can be characterised as an economically viable aquifer. As such this aquifer could be utilised as a potential water supply source during construction and possibly as a domestic water supply source for the proposed NPS.

The aquifer comprises minor Quaternary-age soils, calcareous aeolian sands and aeolianite of the Nanaga Formation as well as a prominent but discontinuous cobble layer (Alexandria Formation conglomerate) at the base of the Algoa Group and above the contact with TMG rocks **(**
Figure 2.52). The details of the aquifers are discussed below and the extent of the aquifer indicated in

Figure 2.53.


-35000
-30000
-25000
-20000
-15000
-3775000
-3780000
-3785000
5000
K90D
K90E
K80F
Oyster Bay
Slang Bay
Klippepunt
White Point
Thyspunt
Thysbaai
Scholtskraal
Krommebaai
Sea Vista
Santareme Bay
St Francis Bay
Seal Point
N
Legend
Road -> National
Road -> Arterial
Road -> Main
Non-perennial river
Perennial river
Dams
Marsh/vlei
Non-perennial pan
Perennial pan
Area for Nuclear-1
EIA Corridor
Thyspunt site
Quaternary catchment
Extent of cobble layer (from SSR drilling)
Bodies inferred from aeromagnetic data (Cole & Naude 2007)
Aeolian sand
Uncorrelated
Ceres Subgroup
Gydo Formation
Baviaanskloof Formation
Goudini or Baviaanskloof Formation
Goudini Formation
Goudini or Cedarberg Formation
Cedarberg Formation
Geophysical Interpretation (Cole & Nade, 2007)
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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
GEOLOGY INTERPRETED STRUCTURES AND MAGNETIC BODIES AT AND SURROUNDING THE THYSPUNT SITE
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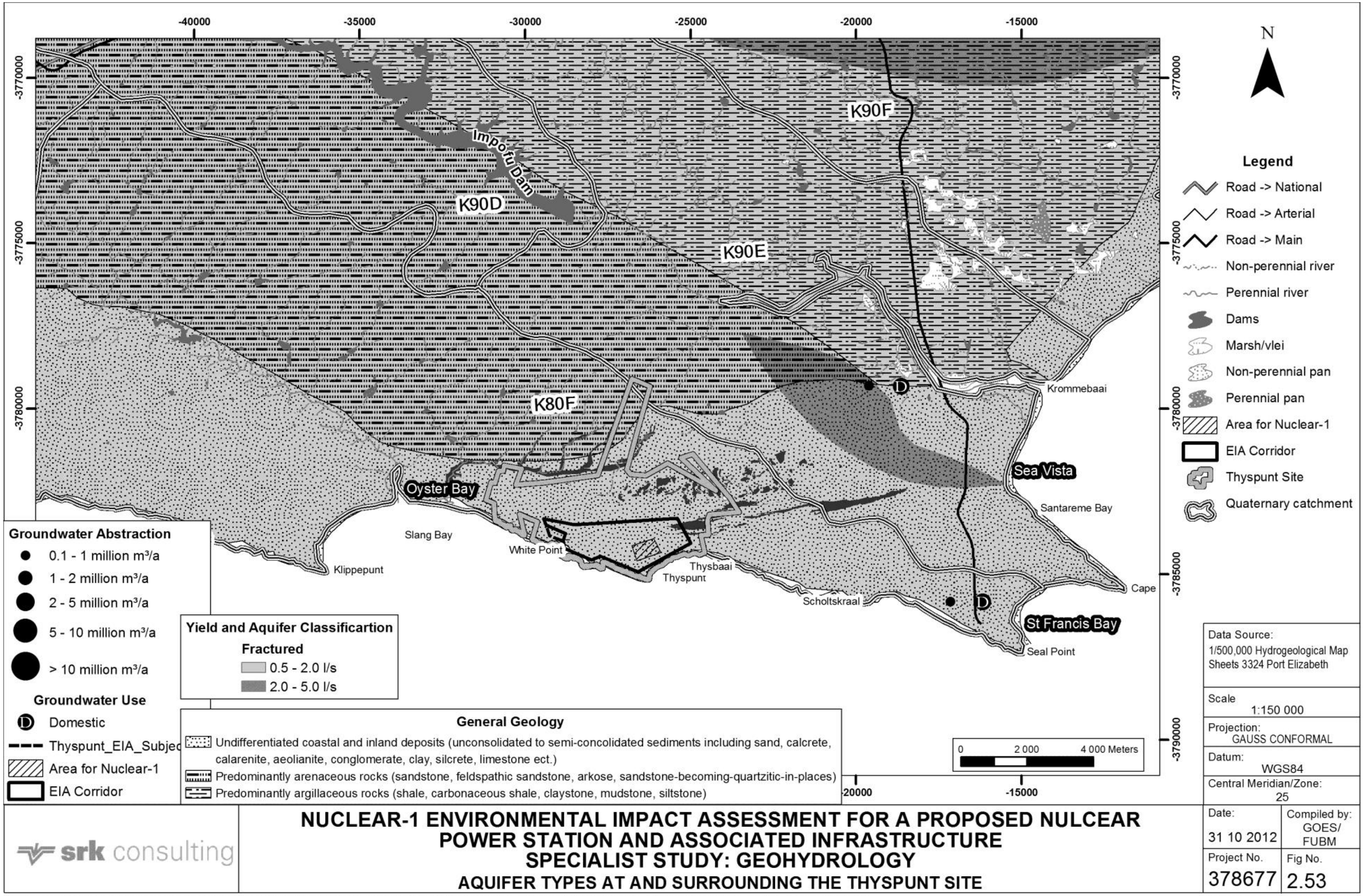

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At the site, the thickness of the aeolian sand varies from 1 to 2 m along the coast to >50 m in the topographically higher-lying dunes. The dune field to the north of the site typically shows aeolian dunes in excess of 100 m high. Several layers of calcretised and consolidated aeolianite were encountered within the Nanaga Formation. These aeolianite beds occur below windblown sands and vegetated dunes and are also visible as outcrops along the coastal dunes and overlying the TMG along the coast.

The cobble layer found at the base of the Algoa Group varies in thickness from 3 m to <1 m close to the beach. It comprises well rounded quartzitic and arenaceous sandstone (10 to *c*.150 mm ø), fine to coarse sand and shells, and is classified as a marine / estuarine / lagoon deposit. The presence of the shelly material indicates the cobble layer is most likely a marine beach deposit or a palaeochannel of a fossil drainage system similar to the palaeochannel of the Sand River north-east of the site. The presence of both the aeolian sands and the cobble layer could also result in the intergranular aquifer being referred to as a heterogeneous aquifer due to the presence of two layers of varying grain sizes as well as envisaged noticeable differences in the horizontal and vertical K values.

Table Mountain Group Aquifer

The secondary aquifer at the site comprises quartzitic sandstones of the TMG. This can be further broken down into two areas: that underlying and surrounding the footprint, which comprises quartzitic sandstone interbedded by arenaceous shale of the Skurweberg and Goudini formations (Nardouw Sub-group) and the area to the north-west of the proposed footprint which comprises fractured quartzitic sandstone of the Peninsula Formation. For purpose of easy reference these will be referred to as the Nardouw and the Peninsula aquifers.

2.3.4 Hydraulic Properties

Algoa Aquifer

A summary of the hydraulic parameters is presented in **Table 2.27**.

The T and K values indicated are relatively high and reflect the good aquifer potential in this area.

Table 2.27: Summary of Hydraulic Parameters for the Algoa Aquifer, Thyspunt Site

Borehole Number	T (m^2/d)	S_y	K (m/d)	Assumed Porosity (%)	Maximum Test Yield (L/s)	Recommended Sustainable Yield (L/s)	Comments
THY-MR1	5	3.0×10^{-1}	2	30	0.2	0.05	Low yield allowed two steps only, therefore T and S values unreliable
THY-MR2	60	5.0×10^{-2}	3	30	4.5	2.0	Sustainable yield calculated with FC, CJ and Theis Methods
THY-MR5	80	2.3×10^{-1}	7	30	2.6	1.0	Yield might increase if boreholes are constructed as production boreholes. Ingress of fine sand during yield test
THY-MR6	240	3.0×10^{-1}	15	30	2.2	2.0	Yield might increase if boreholes are constructed as production boreholes. Ingress of fine sand during yield test
THY-MR11	670	9.0×10^{-2}	223	30	9.5	6.7	Yield test conducted for period of seven days. Time / distance drawdown method used to calculate aquifer parameters. Sustainable yield estimated on groundwater inflow

Table Mountain Group Aquifer

A summary of the hydraulic parameters (some assumed) is presented in **Table 2.28**. The T and K values are much lower than for the Algoa Aquifer and are also relatively low for the TMG Aquifer.

Table 2.28: Summary of Hydraulic Parameters for the TMG Aquifer, Thyspunt Site

Borehole Number	T (m^2/d)	S	K (m/d)	Assumed Porosity (%)	Maximum Test Yield (L/s)	Recommended Sustainable Yield (L/s)	Comments
THY-RP8	15	6.3×10^{-3}	0.17	5	8.02	2.50	Sustainable calculations with FC method
THY-RP10	2	2.9×10^{-3}	0.04	1	1.20	0.10	Ingress of sand during yield test. Yield might increase if boreholes are constructed as production boreholes
THY-RP11	10	1.4×10^{-3}	0.97	1	3.03	0.80	Sustainable calculations with FC method

2.3.5 Borehole Yields

Algoa Aquifer

Boreholes drilled in the Algoa Aquifer revealed high blow yields ranging from 5 to 10 L/s, especially where the basal cobble layer is well developed. In comparison, boreholes that only intersected the fine grained sand revealed much lower blow yields, from 0.1 to 0.8 L/s. Yield testing of the latter boreholes, however, also showed that much larger volumes of water can be abstracted from the aeolian sands. For example, borehole THY-MR2 was pumped at 5 L/s during the step drawdown test without achieving significant drawdown (estimated to represent 23 per cent of available drawdown). These high yields could not be sustained during the constant discharge test, because of the ingress of fine sand into the borehole.

Boreholes with aeolian sands, as well as the cobble layer gave moderate to high yields (from 2 to 5 L/s).

Sustainable abstraction rates from boreholes were calculated by using the FC, CJ and Theis methods. These rates range from 0.05 to 2.0 L/s in the aeolian sands and 2.0 L/s in the combination of the aeolian sands and the cobble layer.

It should be noted that the drilling and yield testing of exploratory boreholes for this EIA can have had no effect on water levels or yields of privately owned boreholes/wells or springs on adjacent properties. This assertion is borne-out by the results of the detailed monitoring programme and observations/measurements during the drilling and yield testing. There was also no risk of the shallow aquifer 'draining away' into the underlying bedrock as the latter aquifer is saturated and contains groundwater under pressure from the main recharge zone in the Karedouw Mountains to the northwest.

Table Mountain Group Aquifer

The Nardouw Aquifer was intersected just below the Algoa Aquifer at depths varying from 2 m below ground level along the coast to about 55 m below ground level towards the inland dunes. This aquifer is highly fractured with water bearing fractures encountered at depths varying from *c*.20 to *c*.110 m below ground level. The fractures are moderate to high yielding with airlift yields ranging from 2 to <5 L/s.

The Peninsula Aquifer was only intersected in the areas north-east and north-west of the footprint area. Two boreholes were drilled to intersect the Peninsula Formation. The results from THY-RP2 showed that the aquifer is highly fractured from 18 m to 55 m below ground level. The airlift yield of the borehole was measured at 6.9 L/s.

2.3.6 Recharge

The effective recharge in the study area is estimated to average 23.8 Mm^3/a. A study done by SRK (Maclear, 2002) calculated the recharge in the K80F quaternary catchment to be 10 per cent of MAP. The Thyspunt area was evaluated by subdividing it into GRUs based on geological and geohydrological considerations. These units represent areas where the broad geohydrological characteristics, i.e. groundwater occurrence and quality, hydraulic properties, flow regime and aquifer boundary conditions are anticipated to be similar.

For the purposes of the evaluation of the site and the preparation of this report, aquifer recharge refers to the amount of rainwater that infiltrates into the vadose zone (i.e. the unsaturated zone above the water table where interstices contain a combination of air and water) and then actually passes into the underlying aquifer, i.e. effective recharge.

The average effective recharge in the Thyspunt site area has been estimated using a grid based modelling technique. Recharge estimates so obtained range between 7.1 (dry years) to 11.6 Mm^3/a (wet years), with an estimated mean of 9.3 Mm^3/a, which equates to an average recharge of about 11 per cent of the mean annual precipitation (MAP) (**Figure 2.55**). This correlates well with previous studies carried out by SRK on the K80F quaternary catchment. The variability of the mean annual groundwater recharge within the GRUs is summarised in **Table 2.29**.

Table 2.29: Mean Annual Effective Recharge for the Thyspunt Area

Groundwater Management Unit	Area (m^2)	MAP (mm)	Recharge Factor (%)	Average		Dry Season		Wet Season	
				Mean Annual Recharge (m^3/a)	Mean Annual Recharge (mm/a)	Mean Annual Recharge (m^3/a)	Mean Annual Recharge (mm/a)	Mean Annual Recharge (m^3/a)	Mean Annual Recharge (mm/a)
K80F-1	111 185 778	362	11.7	4 716 256	42	3 561 936	32	5 870 565	53
K80F-2	69 688 085	366	11.5	2 941 952	42	2 245 803	32	3 646 290	52
K80F-3	4 132 717	403	9.5	1 657 047	38	1 334 992	31	2 154 216	50
TOTAL	224 006 580			9 315 255		7 142 732		11 671 070	
AVERAGE		377	10.9						

2.3.7 Depth to Groundwater

Algoa Aquifer

Groundwater levels measured in the boreholes penetrating this aquifer varied from 0.2 to 25.9 mbgl. The groundwater level elevations in the aquifer to the north of the EIA Corridor are between 17 and 33 mamsl, while in the Corridor Area levels vary between 5 and 9 mamsl. No major fluctuations were observed in the groundwater levels measured during the drilling programme. Data loggers are installed in several of the boreholes to measure groundwater fluctuation with seasonal and tidal variations. The results of water level monitoring in the 11 boreholes and six piezometers from May 2008 until June 2012 are shown in **Figure 2.54**. Water levels in all the boreholes around the Langefonteinvlei show a rise of 2 to 3 m after the good rains of May to August 2011. The water level in borehole THY-WBMR1, which is located west of the Langefonteinvlei in the Algoa Aquifer, started rising approximately three months later than those in the other boreholes situated closer to the vlei, i.e. a delayed recharge. Similar behaviour can be seen in the other monitoring boreholes in the Algoa Aquifer, i.e. THY-MR5, -MR6, -MR8, -MR9 and -MR11. The explanation for this behaviour is postulated to be that recharge to the Algoa Aquifer predominantly occurs in the mobile dune field located inland of the boreholes, where extensive pools are formed by the rising water table 'daylighting' in depressions between the dunes after good rains. Run-off from the TMG rocks inland of the dune field also accumulates behind this dune-field where part of it percolates into the Algoa Aquifer. Due to the low T of the Algoa Aquifer, this recharge pulse takes time to migrate through the aquifer towards the coast.

The water level in THY-WBMR1 and those in the other Algoa Aquifer monitoring boreholes were still rising at the end of March 2012. In comparison, the water levels in the wetland boreholes near the Langefonteinvlei, and the TMG Aquifer boreholes, were stabilising or had already started to decline again. This is an indication that different aquifer conditions exist at THY-WBMR1 than at the other boreholes around the Langefonteinvlei.

THY-WBMR1 shows similar water level behaviour to the other SSR boreholes drilled into the Algoa Aquifer, i.e. THY-MR5, -MR6, -MR8, -MR9, -MR11 and -MR11-M2. These are all drilled into the Algoa Aquifer where the basal cobble layer is present and are further away from the recharge zone represented by the unvegetated Oyster Bay dune field. The water levels in the wetland piezometers also show a similar rise. The ranges of water level variation are summarised in **Table 2.30**. The highest water level rise (4 m) in the Algoa Aquifer was recorded at THY-MR11, which is closest to the coast and the proposed NPS footprint.

Table 2.30: Summary of Water Level Variation in the Algoa Aquifer Monitoring Boreholes at Thyspunt

Aquifer	Water Level Range (m bgl)	Difference in Water Level between Dry and Wet Seasons (m)
Algoa Aquifer in Oyster Bay dune field (Recharge zone)	0 - 3.0	3.0
Algoa Aquifer beneath Langefonteinvlei	2.7 - 3.7	1.0
Algoa Aquifer south of Langefonteinvlei	9.0 - 11.0	2.0
Algoa Aquifer at the proposed nuclear installation footprint (Near the coastal discharge zone)	4.0 - 8.0	4.0

Table Mountain Group Aquifer

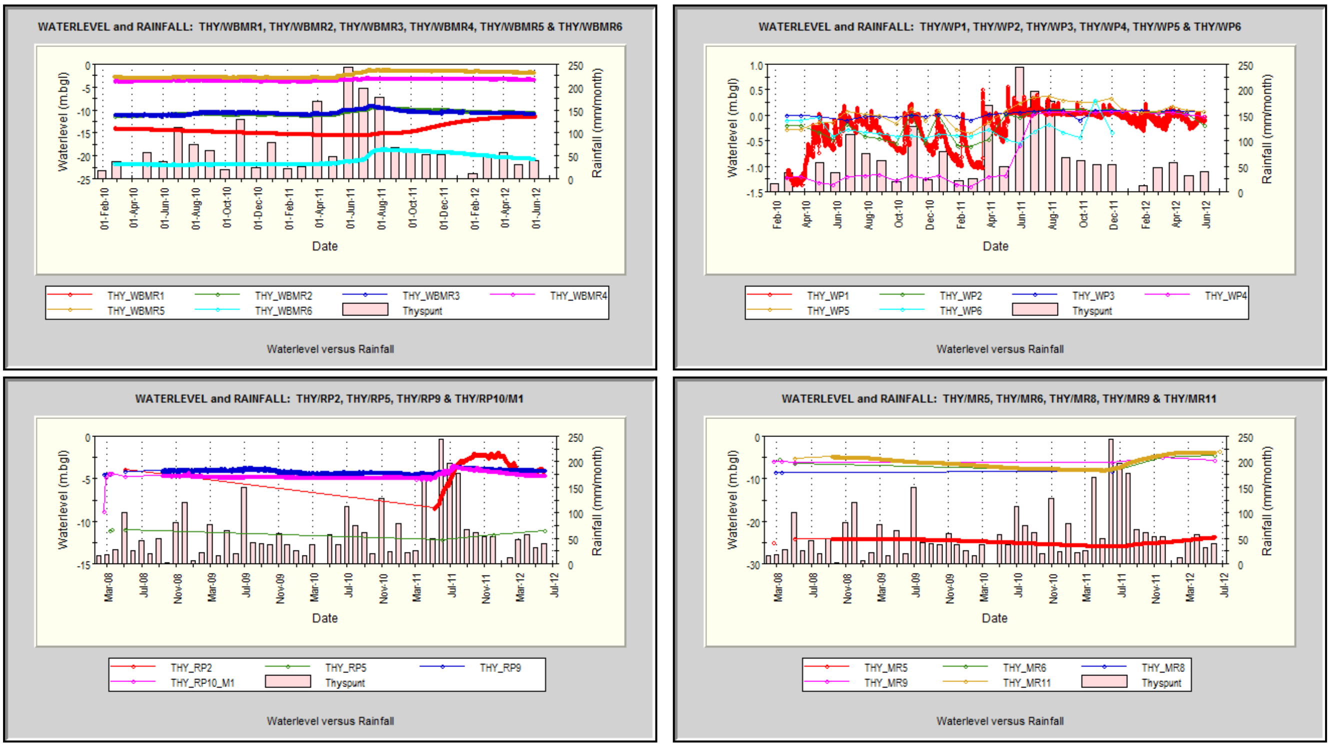
Groundwater levels measured in the aquifer varied from 2 to 12 mbgl. Groundwater elevations in the boreholes covering the aquifer to the north of the proposed footprint area are approximately 30 mamsl while the groundwater elevations at the footprint areas are between 3 and 9 mamsl. No major fluctuations were observed in the groundwater levels measured during the drilling programme.

Data loggers installed in several of the boreholes measure continuous groundwater level fluctuations with seasonal and tidal variations. Water level monitoring in four boreholes from May 2008 until June 2012 show no significant water level fluctuation in the coastal area, even after heavy rainfall events (**Figure 2.54**). This is considered to be due to the absorptive effect of the overlying primary aquifer sediments. Boreholes THY-RP2, THY-RP9, THY-RP11 and THY-RP10-M1 represent water levels in the TMG aquifer. At THY-RP2, which is just inland of the Oyster Bay dune field and away from the coast and is drilled into the TMG Aquifer, a water level rise of 6 m was been recorded over a five-month period from May to September 2011. This was after the good rains that occurred from April to August 2011. In comparison, the water level rise in the TMG monitoring boreholes, which are located closer to the coast and overlain by the Algoa Aquifer (THY-RP9, THY-RP11 and THY-RP10-M1), was *c*.1.5 m, whilst the overlying Algoa Aquifer water level has risen by approximately 2 to 4 m. The water level behaviour in the different aquifers across the site is summarised in **Table 2.31**.

Table 2.31: Summary of Water Level Variation in the TMG Aquifer Monitoring Boreholes at the Thyspunt Site

Aquifer	Water Level Range (m bgl)	Difference in Water Level between Dry and Wet Seasons (m)
TMG Aquifer just north of Oyster Bay dune field (Recharge zone)	2.0 - 8.0	6.0
TMG Aquifer near the coast (Near coastal discharge zone)	3.5 - 5.0	1.5

Figure 2.54: Water Level Fluctuations in Thyspunt Boreholes, (wetland boreholes top left, wetland piezometers top righ, SSR TMG Aquifer boreholes bottom left and the SSR Algoa Aquifer boreholes bottom right)



2.3.8 Direction of Groundwater Flow

Algoa Aquifer

Data obtained from the groundwater investigation indicates that the flow direction in the primary aquifer is in a south-easterly direction and generally follows the topographic gradient (**Figure 2.56**).

Table Mountain Group Aquifer

Similar to the primary aquifer, flow direction observed in the fractured aquifer is in a south-easterly direction.

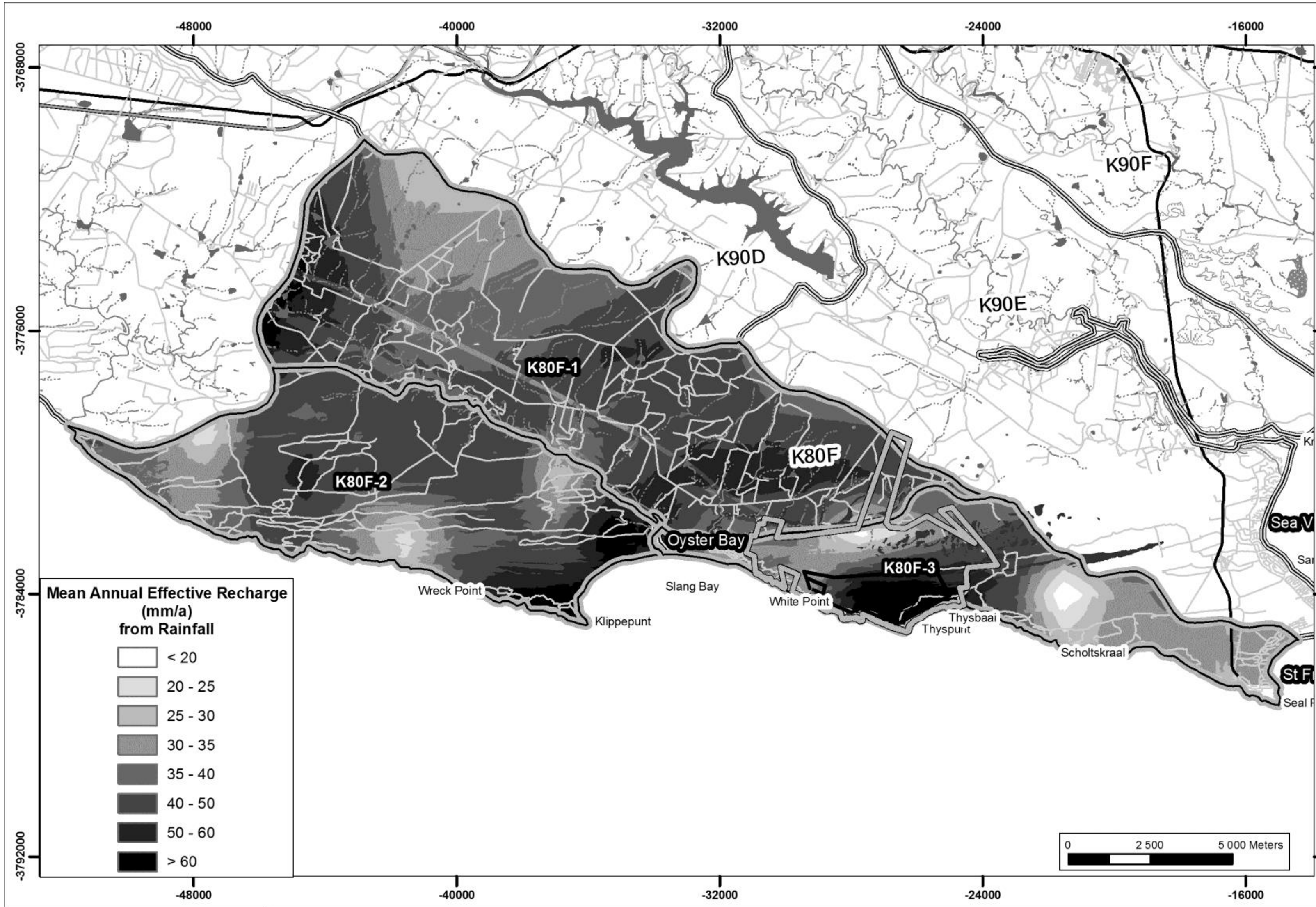
2.3.9 Hydraulic Gradient

Algoa Aquifer

The hydraulic gradient across the site is calculated to be *c*.0.02. Groundwater therefore flows under a relatively low gradient towards the coast.

Table Mountain Group Aquifer

The hydraulic gradient across the site is calculated to be 0.01. Groundwater therefore flows under a relatively low gradient towards the coast.



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1/50,000 Topographic Map Sheets 3318 CB-DA-CD-DC

Scale 1:170 000

Projection: GAUSS CONFORMAL

Datum: WGS84

Central Meridian/Zone: 25

srk consulting	**NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY**	Date: 31 10 2012 — Compiled by: GOES/ FUBM
	MEAN ANNUAL EFFECTIVE RECHARGE FROM RAINFALL AT AND SURROUNDING THE THYSPUNT SITE	Project No. 378677 — Fig No. 2.55

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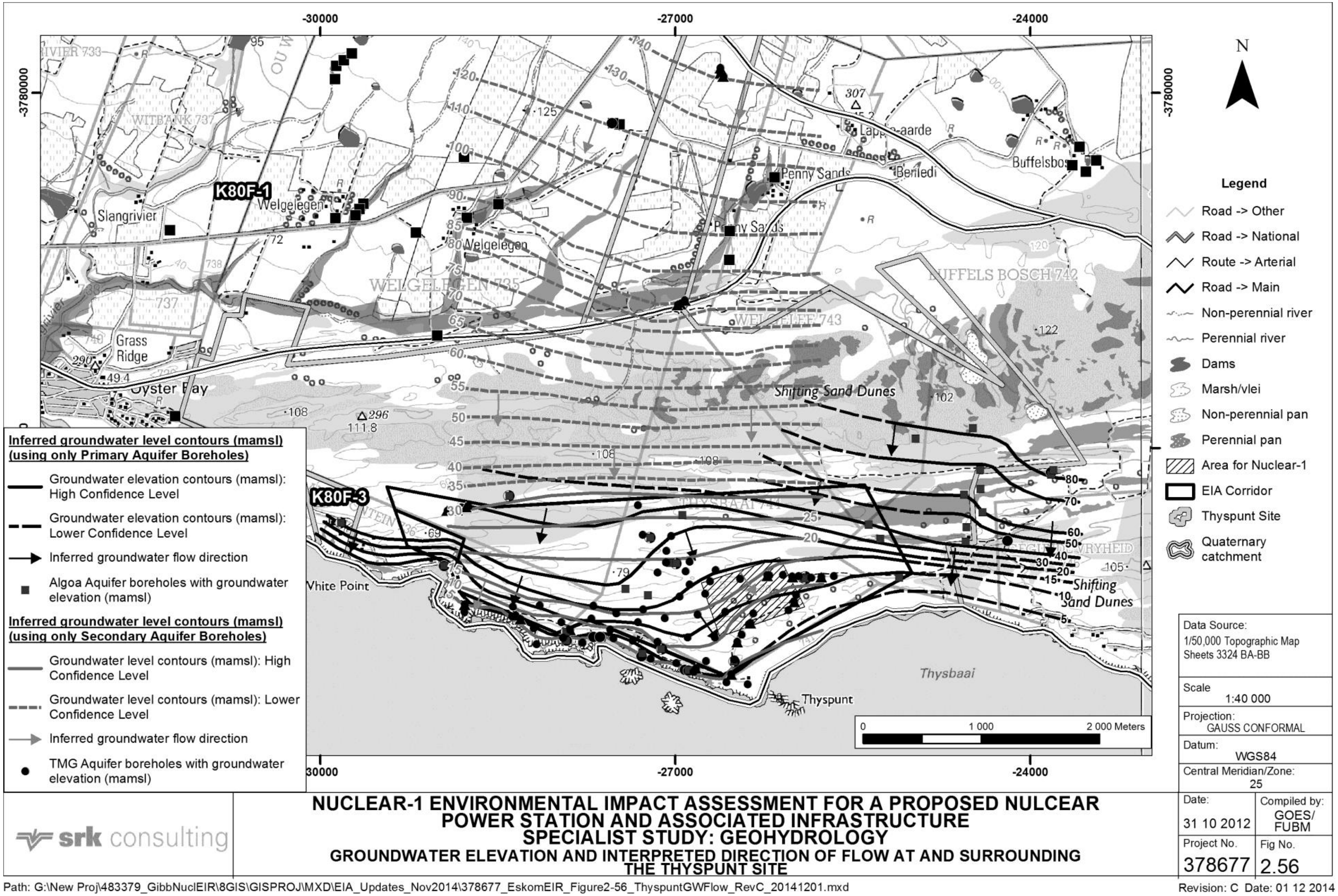
Revision: C Date: 01 12 2014



-30000
-27000
-24000
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N
K80F-1
K80F-3
Slangrivier
Welgelegen
WELGELEGEN 735
WITBANK 737
Grass Ridge
Oyster Bay
White Point
Penny Sands
Lapp-aarde
Buffelsbos
BUFFELS BOSCH 742
THYSBAAI 741
Shifting Sand Dunes
Thysbaai
Thyspunt
Legend
Road -> Other
Road -> National
Route -> Arterial
Road -> Main
Non-perennial river
Perennial river
Dams
Marsh/vlei
Non-perennial pan
Perennial pan
Area for Nuclear-1
EIA Corridor
Thyspunt Site
Quaternary catchment
Inferred groundwater level contours (mamsl) (using only Primary Aquifer Boreholes)
Groundwater elevation contours (mamsl): High Confidence Level
Groundwater elevation contours (mamsl): Lower Confidence Level
Inferred groundwater flow direction
Algoa Aquifer boreholes with groundwater elevation (mamsl)
Inferred groundwater level contours (mamsl) (using only Secondary Aquifer Boreholes)
Groundwater level contours (mamsl): High Confidence Level
Groundwater level contours (mamsl): Lower Confidence Level
Inferred groundwater flow direction
TMG Aquifer boreholes with groundwater elevation (mamsl)
0
1 000
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Data Source:
1/50,000 Topographic Map Sheets 3324 BA-BB
Scale
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Projection:
GAUSS CONFORMAL
Datum:
WGS84
Central Meridian/Zone:
25
srk consulting
NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
GROUNDWATER ELEVATION AND INTERPRETED DIRECTION OF FLOW AT AND SURROUNDING THE THYSPUNT SITE
Date:
31 10 2012
Compiled by:
GOES/ FUBM
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Revision: C Date: 01 12 2014

2.3.10 Rate of Groundwater Flow

Algoa Aquifer

Groundwater is estimated to flow towards the coast at a rate of between 2 to 3 m/d. This rate may vary between different horizons (different grades of sand and cobble layer). The flow rate in the cobble horizon will be higher than in the aeolian sands, due to the higher T/K of this horizon. This may also result in varying flow across the site as the lithological units are not homogeneous (within the primary aquifer).

Table Mountain Group Aquifer

The rate of flow through the TMG Aquifer is estimated to be <1 m/d. The reason for this is a combination of the low hydraulic gradient and low T/K. Connectivity, size and length of fractures will also play a role although no large-scale water-bearing fractures were encountered during the drilling programme. Groundwater flow rates might also vary between the Peninsula and Nardouw aquifers, as the composition and K within these two units differs.

2.3.11 Groundwater Quality

Algoa Aquifer

Electrical conductivity (EC) and pH profile logs were run in the yield-tested boreholes (**Figure 2.57**). Measured EC values varied from 51 mS/m to 82 mS/m (relatively good quality) and the pH values were neutral to slightly alkaline, varying from 7.1 to 7.9. There was no indication of a freshwater-saline interface that should theoretically be present at the coast. It is likely that this interface is steep and the boreholes were not drilled deep enough to intersect this zone.

The Langelier Saturation Indexes representing the Algoa Aquifer vary from 0.4 to 1.04 indicate that this groundwater is likely to cause scaling rather than being corrosive. Measured SO_4 (attacks concrete) concentrations were generally low, i.e. < 100 mg/L.

Figure 2.57: EC Profile of Borehole THY-RP7, Thyspunt Site

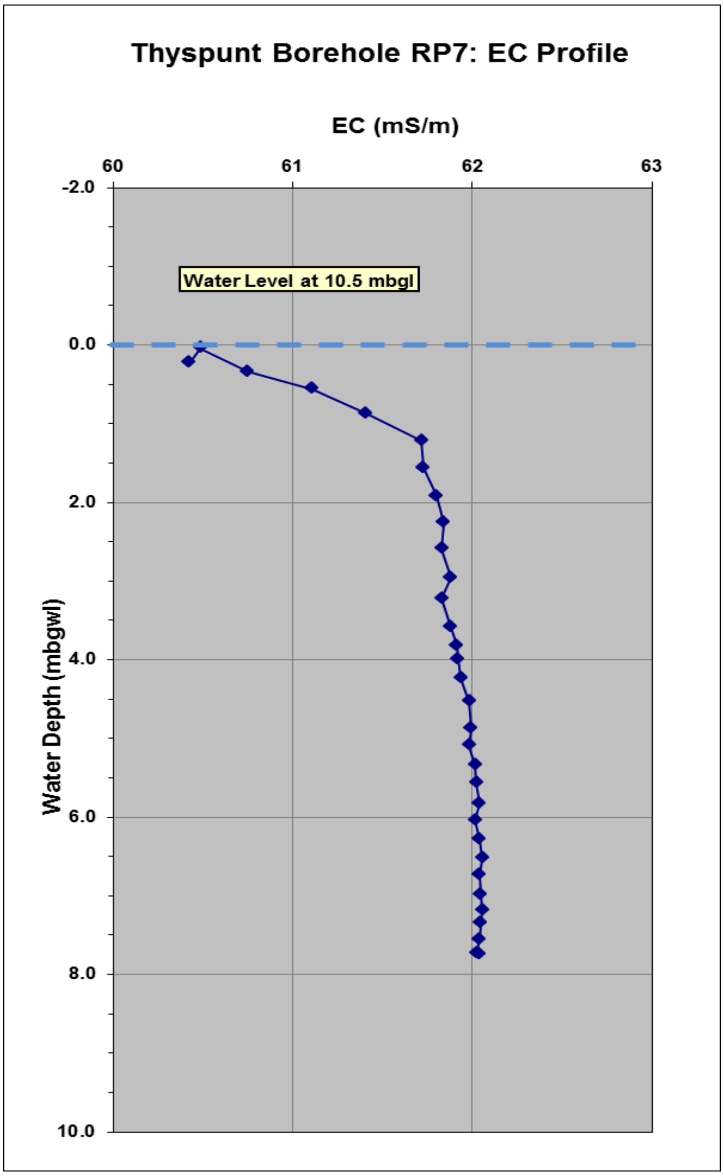
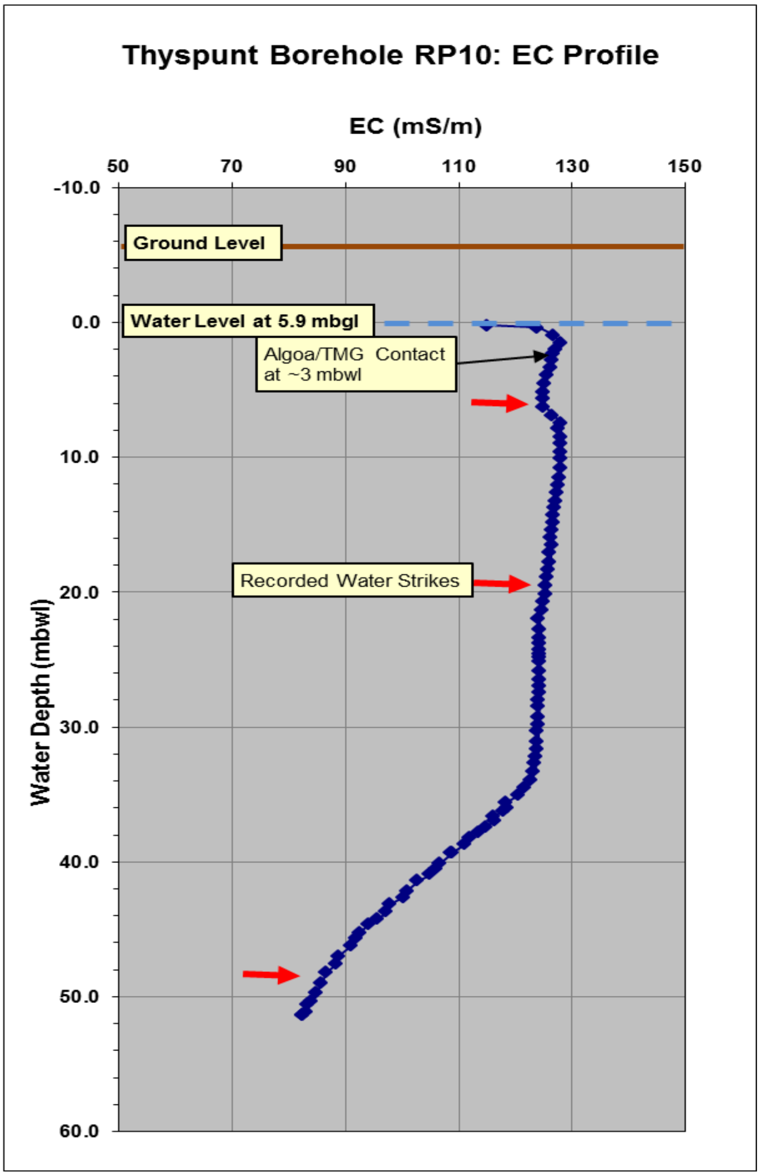


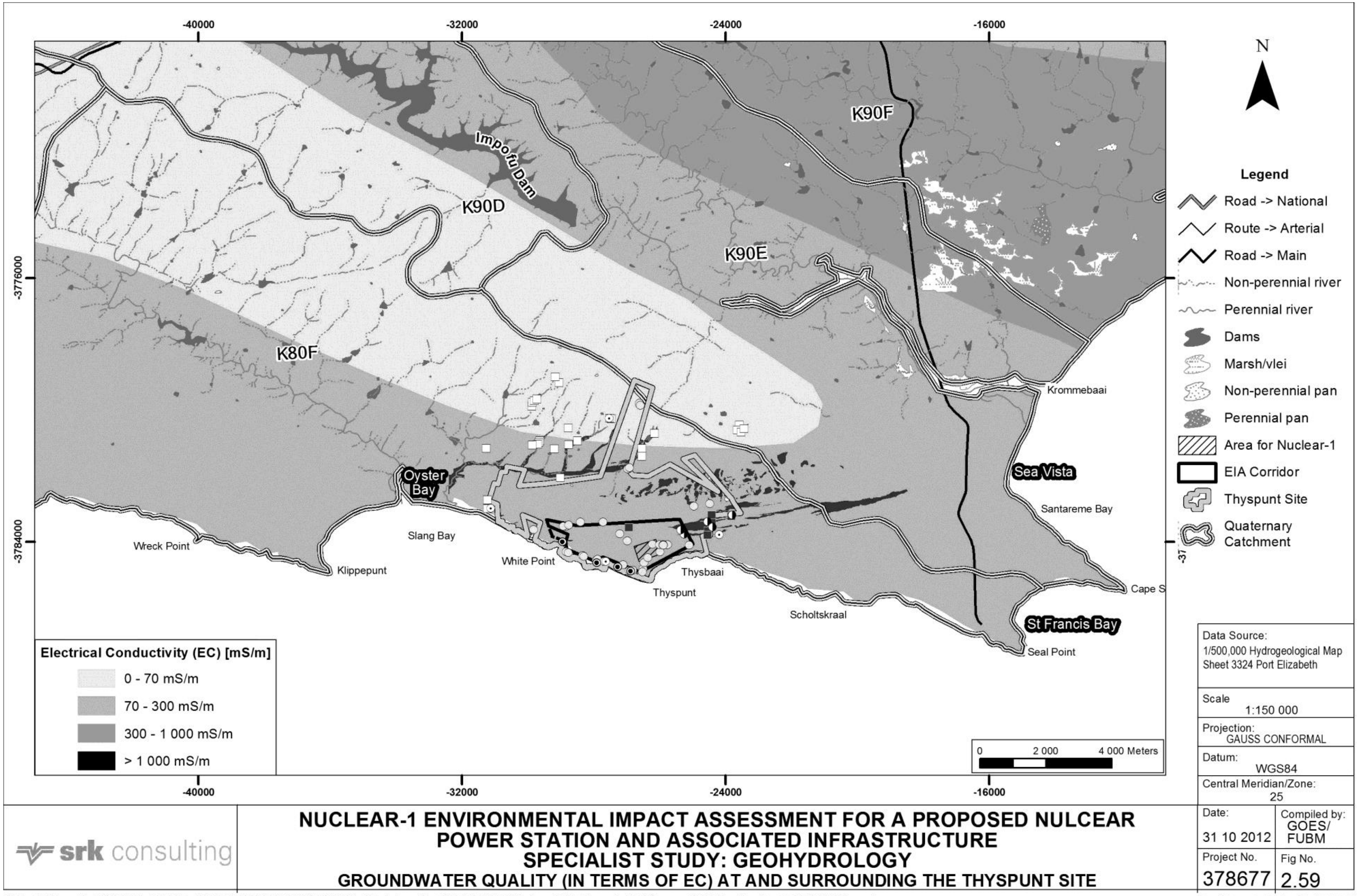
Table Mountain Group Aquifer

The water quality from this aquifer is moderate, with down-hole EC profiling of the boreholes revealed conductivities to range from 80 to 180 mS/m. Indications are that positions of fractures can also be obtained during down-hole EC profiling (i.e. reduction in conductivity values). An example of a down-hole EC profile with depths in m below water level (mbwl) is shown in **Figure 2.58**.

Better quality groundwater (EC <70 mS/m) is generally associated with the TMG in the mountains to the north. The EC of the spring supplying domestic water supply to the village of Oyster Bay was measured as 82 mS/m during the 2007 hydrocensus.

Figure 2.58: EC Profile for Borehole THY-RP10 in the Nardouw Aquifer, Thyspunt Site





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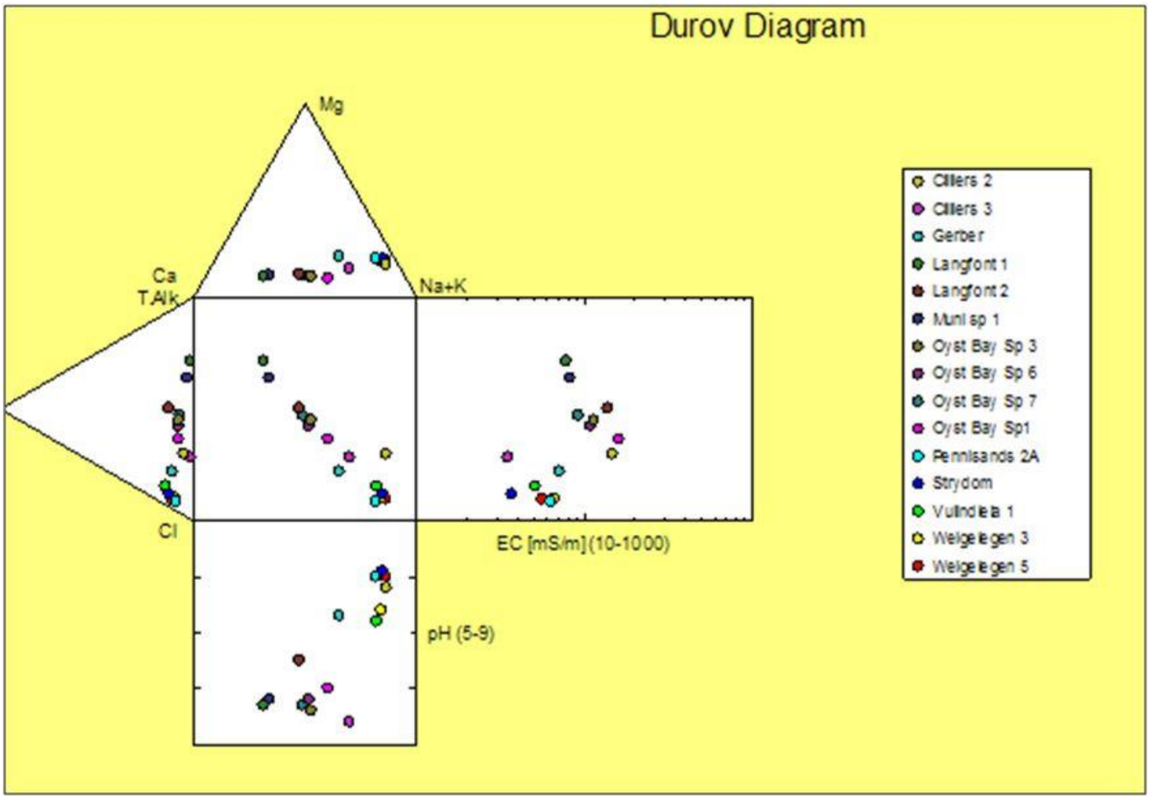
Measurements taken from groundwater recovered from boreholes drilled during the groundwater investigation on site indicate EC values ranging from 56 to 180 mS/m and pH values of 7.2 and 9.4. The regional groundwater quality is shown in **Figure 2.59**.

Chemical characteristics of groundwater from the different aquifers can be summarised as follows:

- TMG Aquifer - alkaline pH, NaCl type with high iron content;
- Algoa Aquifer - neutral to slightly alkaline pH, NaCl type plus high $Ca(HCO_3)_2$.

Figure 2.60: Durov Diagram Showing Macro Chemical Analyses of the Hydrocensus Samples, Thyspunt Site



Chemical analyses of all water samples taken during the hydrocensus are plotted on a Durov diagram in **Measurements** taken from groundwater recovered from boreholes drilled during the groundwater investigation on site indicate EC values ranging from 56 to 180 mS/m and pH values of 7.2 and 9.4. The regional groundwater quality is shown in **Figure 2.59.**

Chemical characteristics of groundwater from the different aquifers can be summarised as follows:

- TMG Aquifer - alkaline pH, NaCl type with high iron content;
- Algoa Aquifer - neutral to slightly alkaline pH, NaCl type plus high $Ca(HCO3)_{2.}$

Figure 2.60. All the groundwater samples have a dominant Na/Cl-SO_4 character with the samples from springs in the Algoa Aquifer showing a trend towards higher HCO_3 and Ca character than groundwater derived from boreholes in the TMG Aquifer.

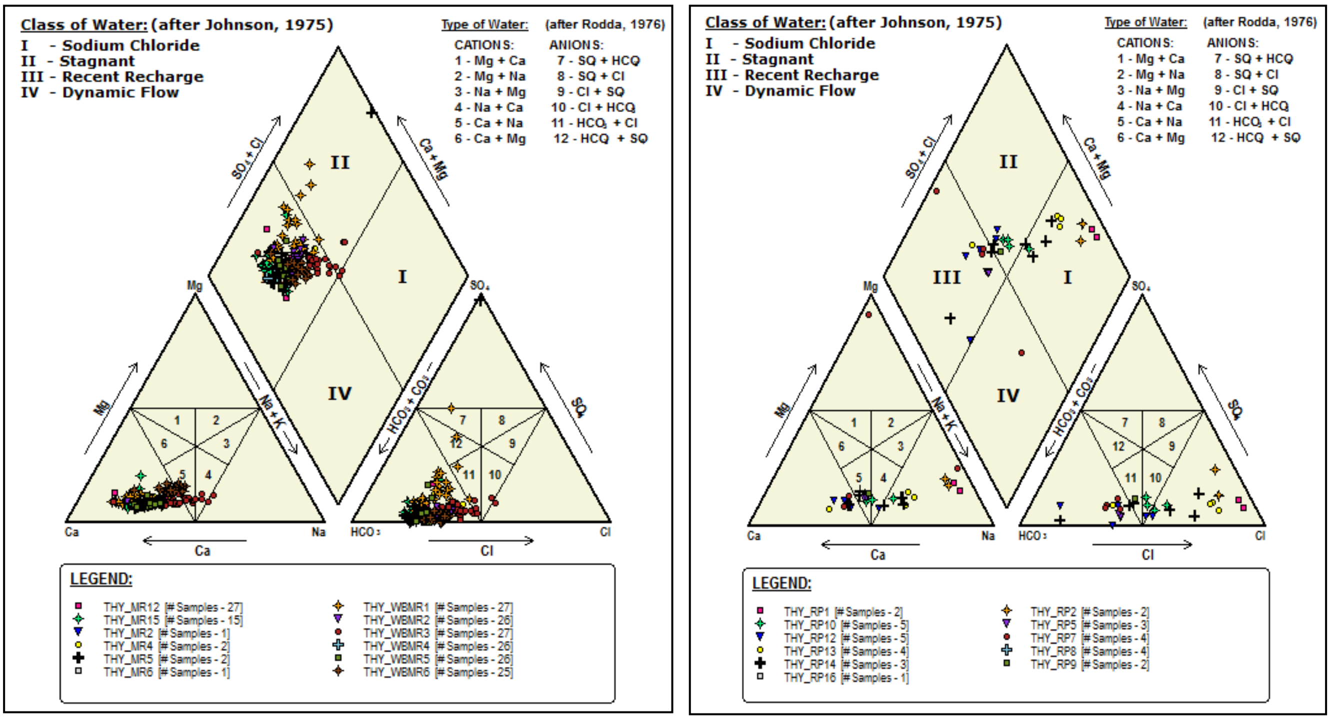
Chemical analyses of all water samples taken during the ongoing monitoring programme are plotted on Piper diagrams in **Figure 2.61**. The Algoa Aquifer samples all show a recent recharge or $Ca(HCO_3)_2$ and minor NaCl signature. The former signature is derived from the $CaCO_3$-rich dune sands while the NaCl influence is due to proximity to the ocean.

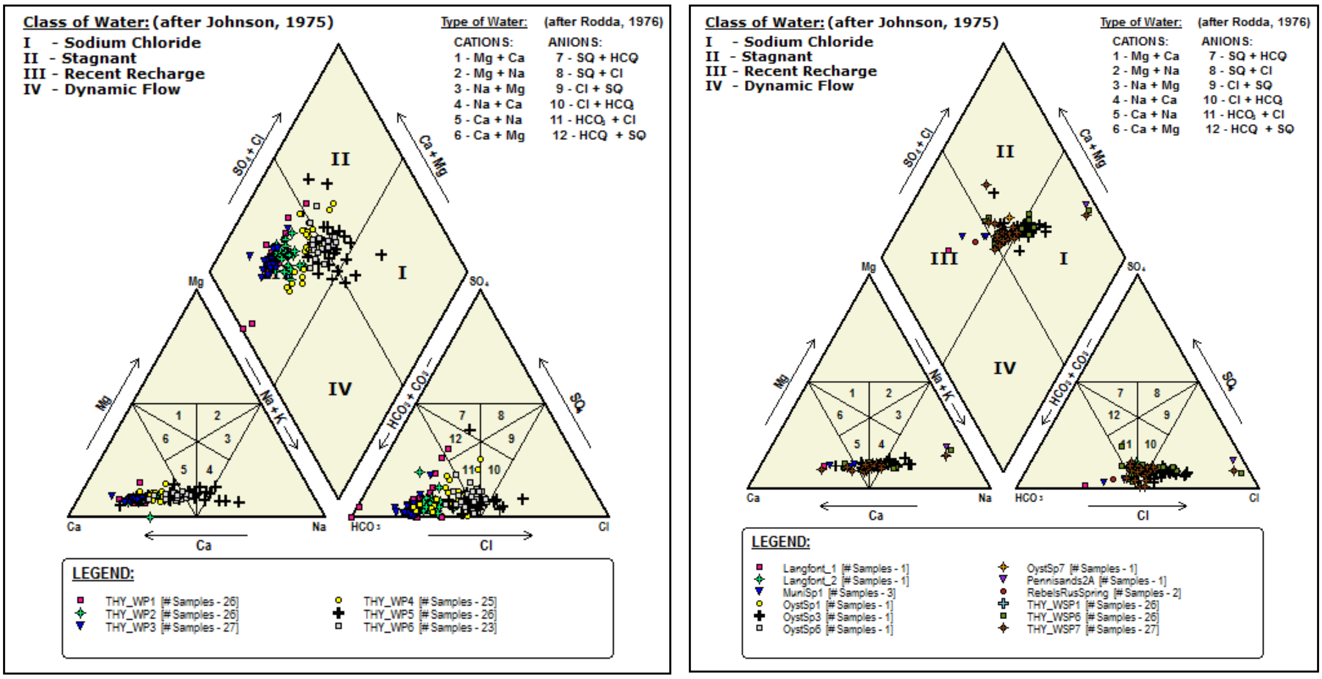
The TMG Aquifer signature ranges from recent recharge to NaCl type. The chemistry of the water in the Langefonteinvlei piezometers shows a predominant $Ca(HCO_3)_2$ and minor NaCl signature and is of a recent recharge type similar to the Algoa Aquifer.

The water from one of the piezometers, WP5, which is located below a house on the slope above the Langefonteinvlei, has a slightly higher Cl and SO_4 content, a typical signature of a slightly stagnant type of water.

The water from the coastal springs shows chemistry similar to the TMG Aquifer thereby suggesting an origin related to this aquifer rather than the Algoa Aquifer.

Figure 2.61: Piper Diagram of Water Samples from the Thyspunt Site (Algoa Aquifer top left, TMG Aquifer top right, Langefonteinvlei Piezometers bottom lef) and Coastal Springs bottom right)





Fifteen groundwater samples were submitted for ^3H, δD and $\delta^{18}O$ analysis. The results of the analyses are presented in **Table 2.32**.

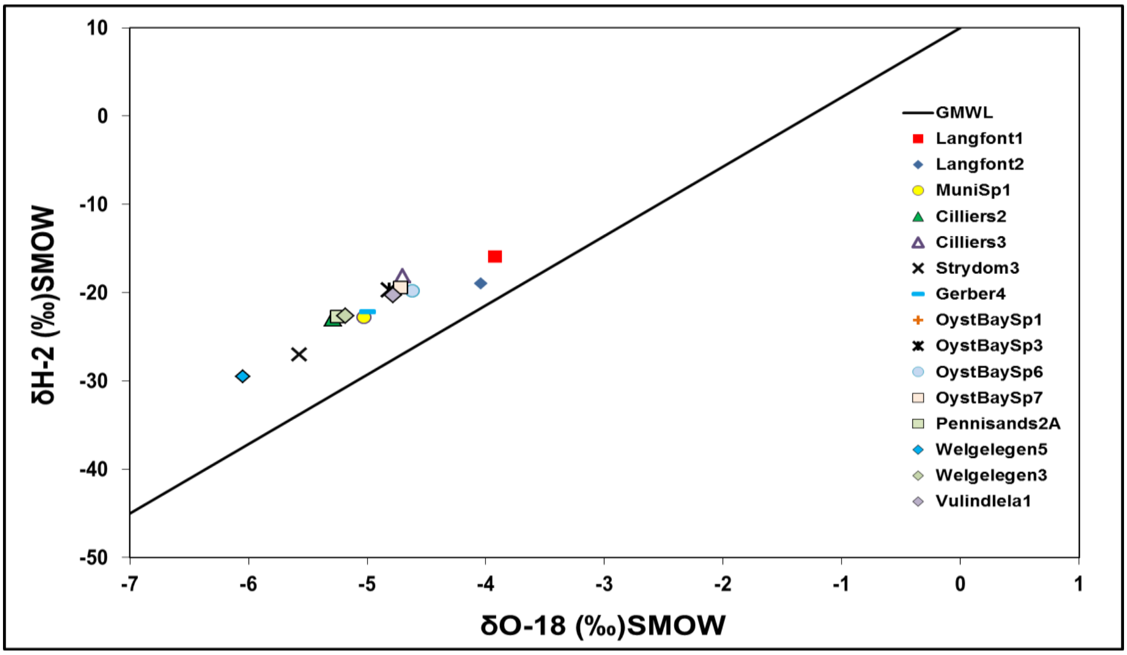
Table 2.32: Summary of Stable Isotope and Tritium Analyses

Borehole Name	Deuterium	Oxygen-18	Tritium	
	δD	$\delta^{18}O$	TU	± **
Langfont1	-15.9	-3.92	1.5	0.3
Langfont2	-19.0	-4.04	2.0	0.3
MuniSp1	-22.8	-5.03	2.3	0.3
Cilliers2	-22.9	-5.29	1.3	0.2
Cilliers3	-18.1	-4.70	1.3	0.2
Strydom3	-27.0	-5.57	1.5	0.2
Gerber4	-22.2	-5.00	0.7	0.2
OystBaySp1	-19.5	-4.71	1.8	0.3
OystBaySp3	-19.7	-4.81	1.3	0.3
OystBaySp6	-19.8	-4.62	1.4	0.3
OystBaySp7	-19.4	-4.72	1.4	0.3
Pennisands2A	-22.7	-5.25	1.6	0.3
Welgelegen5	-29.5	-6.05	1.5	0.3
Welgelegen3	-22.6	-5.18	2.4	0.3
Vulindlela1	-20.3	-4.78	1.7	0.3

** This is the counting statistic for a sample counting a total of 8 hrs

The $\delta^{18}O$ vs. δD samples all plot above the GMWL, which is expected for a Mediterranean-type climate area (**Figure 2.62**). Samples analysed show a uniform $\delta^{18}O$ of -4.72‰ with a variation less than the analytical error of ± 0.1‰.

Figure 2.62: Analysis of $\delta^{18}O$ versus δD, Thyspunt Site



This indicates uniform and localised direct recharge as would be expected from springs arising locally from recharge directly on the dunes (**Table 2.32**). Samples Langfont1 and Langfont2 show the lowest values $\delta^{18}O$ of -3.92 and -4.04‰, respectively. These samples are from springs originating in large vegetated vleis and enrichment is possibly due to recharge from the marsh or vlei.

The isotopic signatures of the groundwater and surface water samples collected during monitoring from the beginning of 2010 to June 2012 are shown in **Figure 2.63**. The groundwater samples plot as a cluster above and roughly parallel to the GMWL (measured with respect to SMOW) but depleted in δD and $\delta^{18}O$.

The surface water samples show largely similar isotopic signatures to those seen in the groundwater samples. This trend of data indicates normal precipitation and recharge processes at the site and surrounding area.

Samples from the Langefonteinvlei (THY-WP1 to -WP5) plot closer to the GMWL as these samples are from a wetland with considerably more direct rain water influence than the spring and groundwater samples. They also show enrichment of the $\delta^{18}O$ isotopes due to evaporation. For reasons unknown, the May 2011 sample for THY-WBMR3 returned anomalous values. However, results for the subsequent analysis reverted to 'normal' and are similar to those prior to May 2011.

2.3.12 Existing Groundwater Contamination

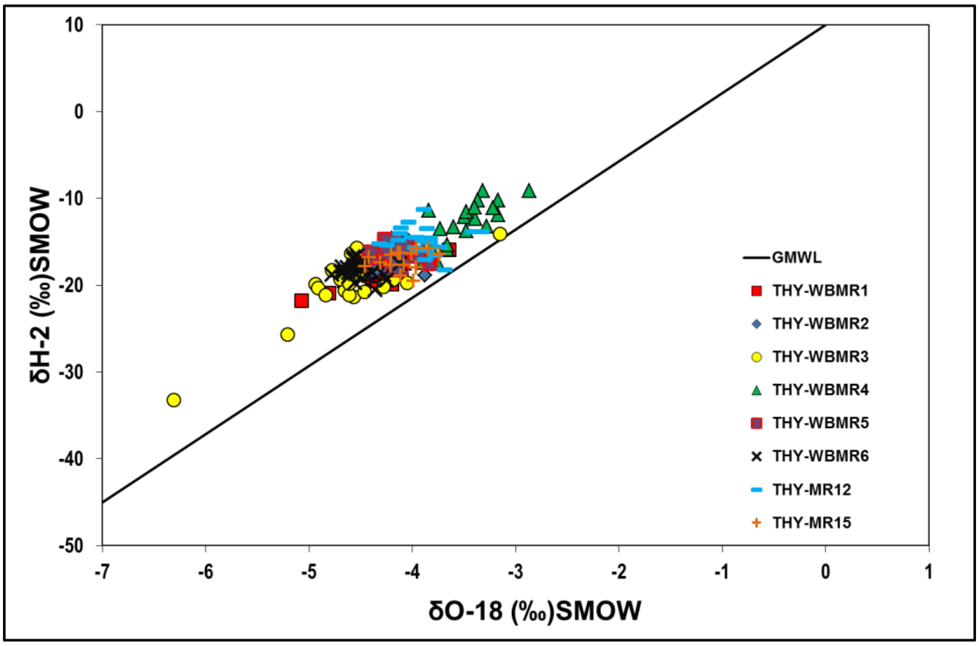
Based on site work carried out during the EIA, there appears to be no existing groundwater contamination at the site. However, there may be potential sources up-gradient and to the north, e.g. fertilisers, animal wastes, septic tanks, etc. The site is located in a pristine area. As there are no existing contamination threats, the quality of groundwater at the site therefore represents ambient conditions.

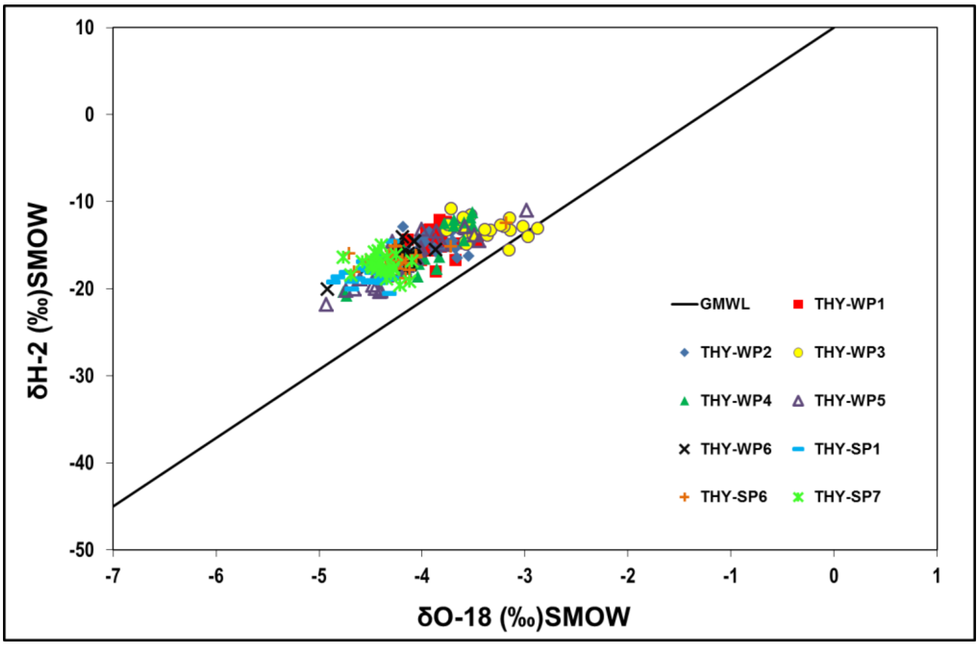
2.3.13 Potential Contamination Pathways

Local pathways for the migration of potential contaminants include the upper intergranular aquifer (Algoa Aquifer) and the lower fractured rock aquifer (TMG Aquifer). Contamination releases may migrate down-gradient through these aquifer systems. The extent of contamination would likely be restricted to within the Corridor Area and coastal springs / seeps.

The probability of leaks of any radioactivity affecting existing groundwater users is unlikely, but air emissions from the site could be transported inland by prevailing winds (regional pathway) and contaminate groundwater by being incorporated into rainfall recharge.

Figure 2.63: Analysis of $\delta^{18}O$ versus δD forGroundwater Monitoring Samples (top) and Wetland/Spring Monitoring Samples (bottom), Thyspunt Site





2.3.14 Groundwater Use

Regional Groundwater Abstraction

A detailed hydrocensus of a 5 km buffer zone surrounding the site was conducted in December 2007. A summary of the numerous boreholes and springs identified in the Oyster Bay area is given in **Table 2.33** and **Figure 2.64.**
Figure 2.64 indicates the location of the boreholes and springs.

Table 2.33: Summary of Hydrocensus Boreholes and Springs, Thyspunt Site

Borehole Name	Latitude Degrees	Longitude Degrees	Surface Elevation: (mamsl)	Source Type	Comments
Bedwell	34.17387°S	24.66125°E	31	Borehole	Equipped, domestic use
Cilliers 1	34.15642°S	24.68812°E	80	Borehole	Equipped, irrigation use
Cilliers 2	34.15177°S	24.68788°E	105	Borehole	Open, unused
Cilliers 3	34.16538°S	24.68534°E	58	Borehole	Open unused
Farm 826	34.15747°S	24.71220°E	93	Borehole	Equipped, domestic & stock use
Gerber 1	34.18390°S	24.74428°E	95	Borehole	Open, artesian stock watering
Gerber 2	34.15254°S	24.74361°E	103	Borehole	Equipped, domestic & irrigation use
Gerber 3	34.15303°S	24.74486°E	99	Borehole	No access, unused
Gerber 4	34.15218°S	24.74580°E	94	Borehole	Open, artesian, unused
Langfontein 1	34.17591°S	24.74160°E	79	Spring	Dammed, domestic use
Langfontein 2	34.18113°S	24.73757°E	61	Spring	Dammed, stock use
Mans	34.09246°S	24.39452°E	50	Borehole	Equipped, irrigation use
Municipal BH	34.17146°S	24.66132°E	30	Borehole	Equipped, domestic use
Oyster Bay Spring 1	34.18865°S	24.69712°E	0	Spring	Sporadic domestic use
Oyster Bay Spring 2	34.18839°S	24.69961°E	0	Spring	Sporadic domestic use
Oyster Bay Spring 3	34.18839°S	24.70017°E	0	Spring	Sporadic domestic use
Oyster Bay Spring 4	34.18294°S	24.68592°E	0	Spring	Sporadic domestic use
Oyster Bay Spring 5	34.19089°S	24.70797°E	0	Spring	Sporadic domestic use
Oyster Bay Spring 6	34.19096°S	24.70828°E	0	Spring	Sporadic domestic use
Oyster Bay Spring 7	34.18984°S	24.70400°E	0	Spring	Sporadic domestic use
Pennisands 1	34.15967°S	24.71216°E	95	Borehole	Equipped, irrigation use
Pennisands 2	34.15339°S	24.71631°E	119	Borehole	Open, unused
Municipal Spring	34.17374°S	24.66240°E	24	Spring	Pumped to reservoir, domestic use
Strydom 1	34.15539°S	24.69102°E	90	Borehole	Open, unused
Charly_Wood	-34.18702°S	24.73859°E	15	Spring	Sporadic domestic use
Sterkfontein	-34.19077°S	24.75103°E	16	Spring	Sporadic domestic use
Rebelsrus Spring	-34.18991°S	24.75478°E	31	Spring	Sporadic domestic use
Strydom 2	34.14933°S	24.70213°E	119	Borehole	Open, unused
Strydom 3	34.14924°S	24.70154°E	122	Borehole	Open, unused
Strydom 4	34.14923°S	24.70143°E	123	Spring	Dammed, stock watering
Vuli'Ndlela 1	34.13938°S	24.68493°E	139	Borehole	Open, unused
Vuli'Ndlela 2	34.15532°S	24.67862°E	82	Borehole	Open, unused
Vuli'Ndlela 3	34.15573°S	24.67828°E	80	Borehole	Equipped, irrigation use
Vuli'Ndlela 4	34.15621°S	24.67790°E	80	Borehole	Open, artesian, unused
Vuli'Ndlela 5	34.15754°S	24.68344°E	84	Borehole	Open, unused
Welgelegen 1	34.15640°S	24.67606°E	79	Borehole	Open, unused
Welgelegen 2	34.14583°S	24.67605°E	87	Borehole	Open, unused
Welgelegen 3	34.14482°S	24.67618°E	108	Borehole	Equipped, unused
Welgelegen 4	34.14437°S	24.67687°E	111	Borehole	Open, unused
Welgelegen 5	34.14388°S	24.67763°E	117	Borehole	Open, unused
Welgelegen 6	34.13777°S	24.68375°E	138	Borehole	Equipped, irrigation use

From the results of the hydrocensus it is evident that groundwater is used extensively for both agricultural (irrigation and stock watering) as well as domestic purposes.

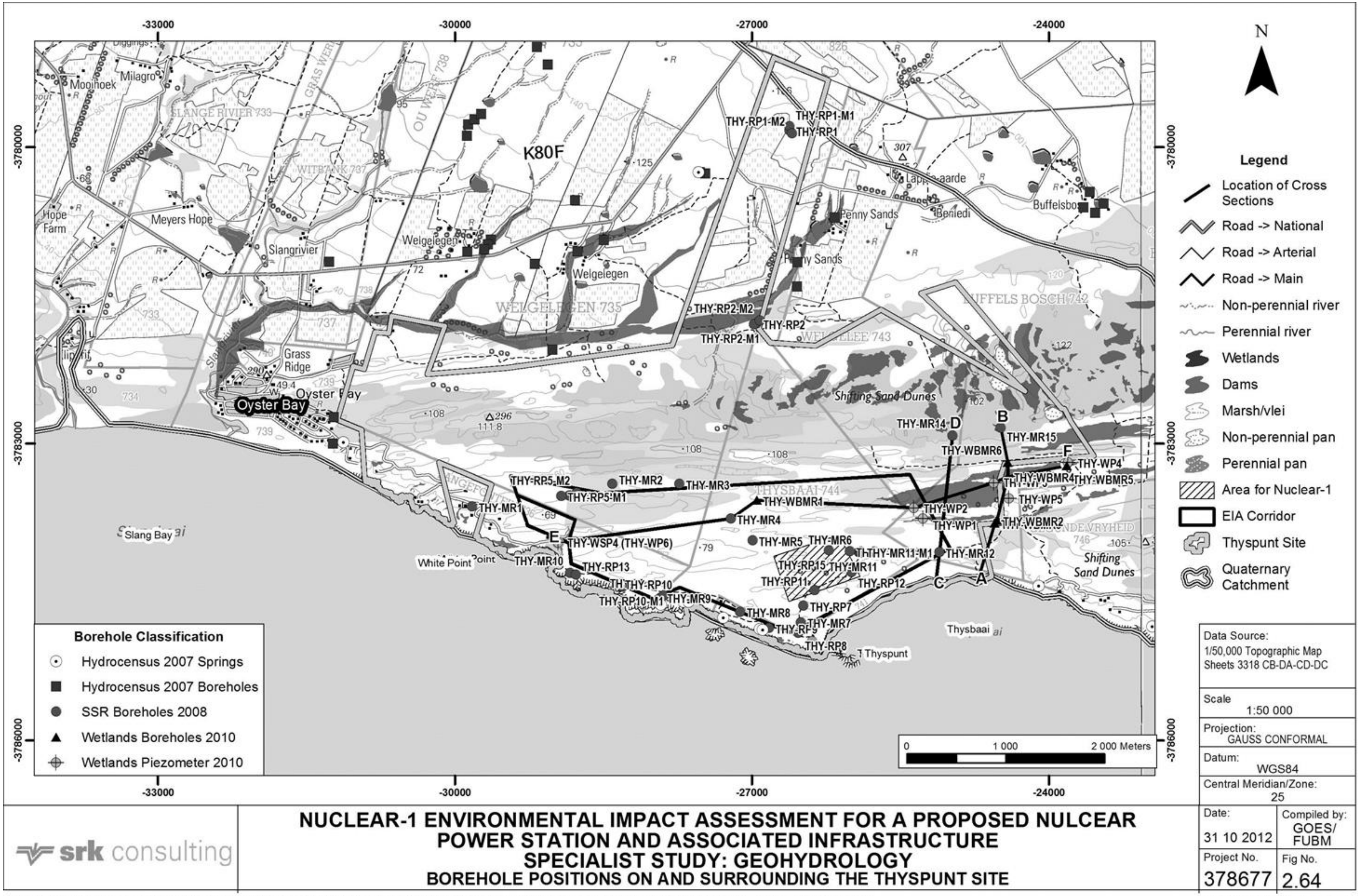
Oyster Bay village relies solely on groundwater (spring and borehole) for domestic purposes. The spring feeding the town reservoir is located to the east of the village and arises in the dune field to the north-east, feeds a wetland and is pumped to the main storage reservoir in the town. The town borehole is located within the north-east part of the village. An estimated 3 Mm^3 per annum is utilised by the village. A number of small springs issue from the base of the vegetated dunes to the east of the site in the Rebelsrus area and are used by the local residents for domestic water supply. One of these springs (Rebelsrus Spring) used by the home owners in the Rebelsrus Nature Reserve east of the site has been included in the monitoring programme.

Water samples were taken at selected boreholes and springs identified during the hydrocensus. The laboratory results suggest that the borehole water from the fractured aquifer falls within Class I (water of an ideal quality for drinking purposes), as specified in the SANS 241:2006 guidelines. The water from the majority of the springs falls in Class II (good water quality for short-term use only) with elevated Na and Ca. Chloride is of Class II in the springs and is not excessively elevated.

On-site Groundwater Abstraction

During the hydrocensus several prominent springs / seeps along the coast that originate from the base of the Algoa Aquifer were identified. Some of these springs currently supply water to the holiday houses (most have now been vacated) on the site. The most prominent flowing spring is located at the Langfontein to the north-east of the Eskom land and flows out (*c*.2 L/s) from below the northern sand dunes in a westerly direction and emerges as a stream at White Point. This water is utilised for domestic purposes and dammed by the residents of three houses on Buffelsbosch 742. The most prominent spring along the coast occurs just west of Thyspunt (THY-SP4) and has been dammed and contains a pump for supply to the fisherman's cabins on site. Monitoring of the flow at this spring from April 2010 to January 2012, when the owner refused further access to the property, indicated flow to range from *c*.7.6 L/s during droughts to *c*.21.3 L/s after heavy rains. The median flow is *c*.11.6 L/s. According to information provided to SRK the majority of springs flow throughout the year with a noticeable increase in flow following significant rainfall events. This has been verified by the site monitoring programme.

Boreholes yield tested on the site are also capable of serving as a sustainable water sources to the proposed NPS for both construction purposes as well as potential domestic water source. Sustainable yields vary from 1 L/s to >5 L/s over 12 hr duty cycles. Eskom now intends to use these groundwater resources for a period of approximately one year prior to commissioning of a permanent desalination plant. The amount required is 17 to 23 L/s, which can be obtained from existing tested boreholes such as THY-MR11, THY-RP2 and -RP4. However, these boreholes are scattered across the site and it would be more economical and make for easier management to obtain the supply from a more concentrated area, probably to the east and west of the footprint (see modelling scenarios). This will require the drilling of additional production and monitoring boreholes under supervision of a hydrogeologist.



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2.3.15 Aquifer Classification and Vulnerability

Algoa Aquifer

The intergranular Algoa Aquifer is currently classified as a Major Aquifer system (Parsons, 1995 and Parsons and Conrad, 1998), as this aquifer produces high yielding boreholes with good water quality. The site is classified as being highly vulnerable to anthropogenic impacts.

Table Mountain Group Aquifer

The TMG Aquifer is classified as a major aquifer system. The aquifer is classified as having a moderate vulnerability to anthropogenic impacts.

Ecosystem Water Use and Interaction with Surface Water

Wetland ecosystems on the site can be split into three main groups, as described below (wetland areas are shown on all appropriate Figures).

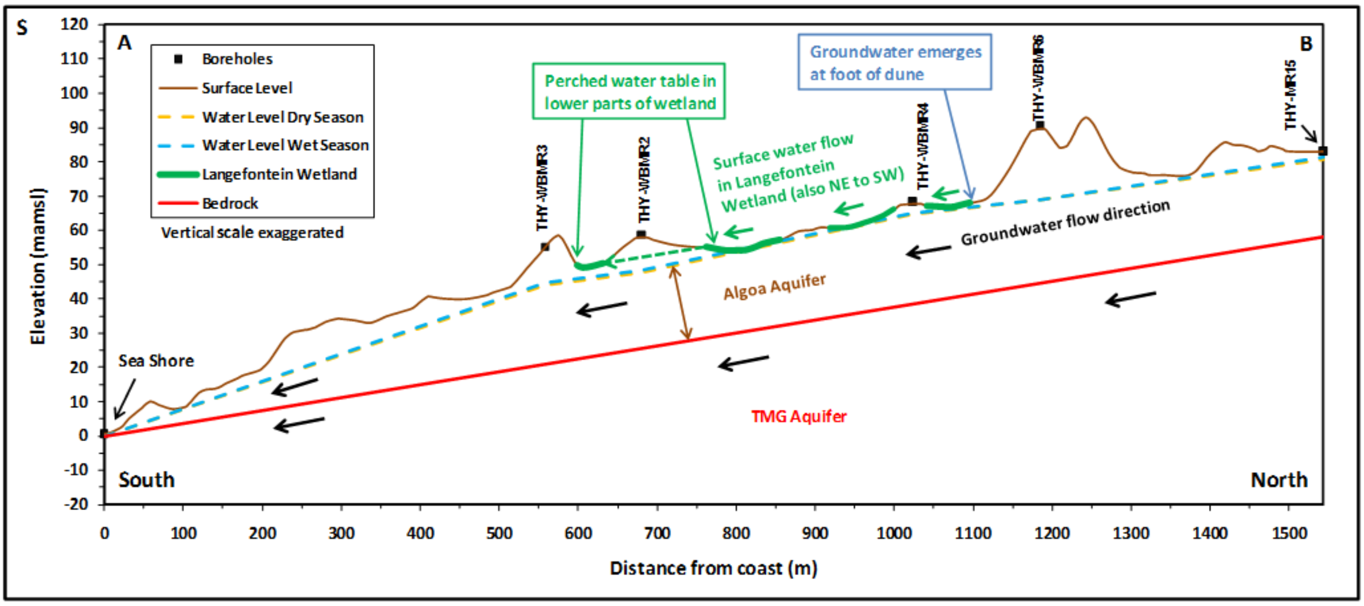
Largely pristine, seasonal dune slack wetlands occur within the lower-lying dunefield of the tall dune line. These wetlands are fed by groundwater, and increase in size during winter with distance eastward. This dune / wetland system is also referred to as the Sand River. Along their northern edge, where alien vegetation increases and farming practices have historically taken place, the wetlands are somewhat more disturbed. These wetlands are believed to be of importance as breeding habitat for several species of frog. They are also probably a regionally rare habitat, since dune slack wetlands are not believed to be extensive in this region.

An expanse of *Prionium serratum* (Palmiet) permanent wetland called the Langefonteinvlei is located in the north-western portion of the site, on the southern edge of the large dune field. In addition to its likely importance as permanently saturated, seasonally inundated marshland habitat, this wetland system is also assumed to be important in terms of its provision of broader wetland ecosystem services, such as maintenance of flow into downstream systems, erosion control and water quality amelioration. The deep layer of humic/organically enriched soils of Langefonteinvlei retains water, and thus acts as a buffer to wetland plants in times of drought. This layer, with its low K, facilitates perching of water above the organic layer, resulting in the extension of wetland conditions westward. The build-up of organic material under saturated conditions probably originally resulted from slow infiltration of groundwater through the fine sand fraction that underlies the wetland, and the resultant slow decomposition of plant material under anaerobic conditions. The abrupt western boundary of the wetland appears to result from rapid drainage through coarse gravel, which prevents the build-up of organic material and results in infiltration to the aquifer, which appears to lie well below the western wetland edge. Results obtained from installation of monitoring boreholes around the Langefonteinvlei, installation of piezometers in the vlei and monitoring of these boreholes and piezometers have indicated that:

- Groundwater flows from north to south across the site, and emerges at the foot of the high dune just north of the Langefonteinvlei, from where it flows into the wetland. Additional flow enters the wetland from the high-lying water divide to the east of the wetland, and flows in a north-east to south-westerly direction.

- From the southern edge of the Langefonteinvlei, the groundwater table slopes steeply away to the coast, because of topographic effects and resultant natural groundwater flow mechanics.
- From the zone at which groundwater 'daylights' in the Langefonteinvlei, it flows partially as surface flow on and in the humic layer of the wetland, towards the south and west.
- In the southern and western portions of the wetland, the water in and on the humic layer of the wetland becomes perched and separated from the underlying groundwater table.
- The downstream extent of the Langefonteinvlei appears to be determined by a balance between inflow and evapotranspiration, rather than by the water table.
- Water stored in the humic layer preserves the wetland through drought periods.
- Water from the higher-lying northern portion of the Langefonteinvlei flows through the dune ridge and into the southern smaller portion of the wetland.
- **Figure 2.65** (SRK, 2011) illustrates the geohydrological model of wetland / groundwater interactions at the Langefonteinvlei, using a north-south cross section through THY MR15, across to THY WBMR3 and the sea (see **Figure 2.64** for cross-section locations).
- The wetlands as a whole are relatively insensitive to changes in groundwater level, at least in the short term, provided that the water table does not drop below the thresholds at which groundwater 'daylights' into the wetland.

Figure 2.65: North-South Cross-Section through Langefonteinvlei, Showing Inferred Surface/ Groundwater Linkages Resulting in wetland Formation and Function, Thyspunt site



Along the coast, numerous freshwater seeps open onto the rocky shores, driven by the contact between the underlying bedrock and the edge of the sandy dunes. These systems are considered to be of high conservation value and potentially contribute to the overall site biodiversity. They may play a role as ecological corridors, facilitating the movement of mammals such as otters and mongooses between the coast and the dune areas. Although fairly common at site level, these seeps are likely to be rare at a regional level, particularly in the relatively pristine state in which they occur at the Thyspunt site. This relative scarcity reflects the extent of development along the Eastern Cape coastline, resulting in degradation, drainage, canalisation or piping of such wetlands and leading to their transformation into *Typha capensis* (Bullrush)-dominated linear channels.

Coastal seeps occur downstream of the proposed power station footprint. . The function of the coastal seeps as habitats could be compromised by construction of the proposed nuclear power station. These wetlands are considered to be relatively insensitive to changes in water table, but vulnerable to salinization (SRK *et al.,* 2012). The water from the coastal springs shows chemistry similar to the TMG Aquifer, thereby suggesting an origin related to this aquifer rather than the Algoa Aquifer (SRK *et al.,* 2012).

Interaction between surface water on the site will most probably be of an indirect, rather than direct nature. This is because of the absence of prominent perennial rivers (or any rivers) on the site. The main influence from surface water will be in the form of runoff that is stored / captured in the lower parts (valleys) in the dune fields. This will then infiltrate the intergranular aquifer. The infiltration of the pooled water will therefore act as recharge to the intergranular aquifer.

2.3.16 Conceptual Model

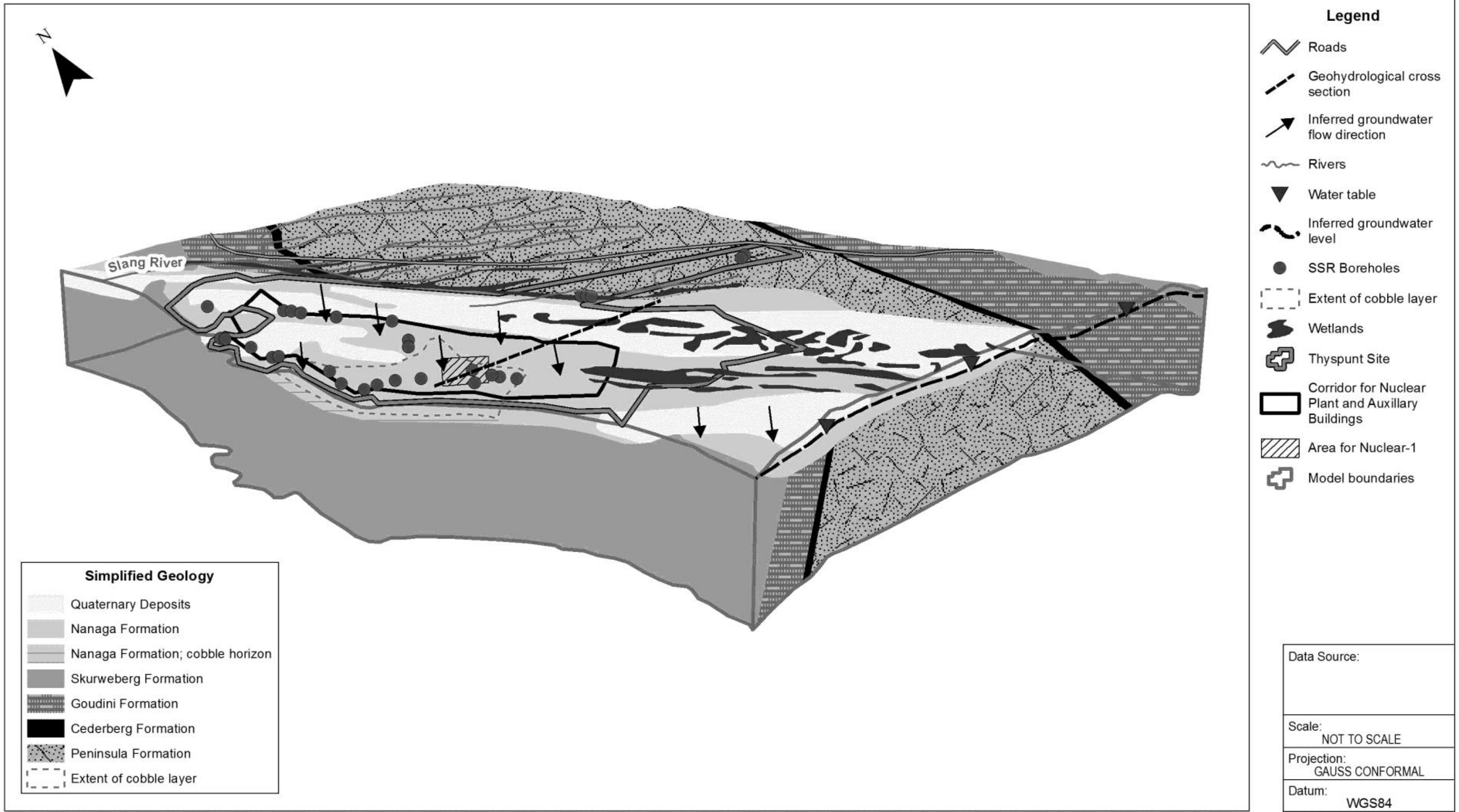
The key features used for the model are (see **Figure 2.66** and the cross-sections shown in **Figure 2.67**, **Figure 2.68** and **Figure 2.69**. Cross-section locations are shown on **Figure 2.64**):

- The topography is undulating with a slope towards the coast and dune troughs and crest occur parallel to the coast;
- No rivers or streams drain the immediate site, but pooling of water occurs in the valleys between the dune crests following heavy rainfall events. The pooled water then infiltrates the primary aquifer and flows to the coast, where it surfaces as springs and seeps;
- The site is underlain by two aquifers i.e. the primary intergranular aquifer which covers a large portion of the site and the deeper lying fractured TMG Aquifer;
- The contact between the two aquifers is characterised by the presence of a prominent cobble layer (base of the intergranular aquifer) and in some areas by a weathered zone comprising silty sandstone (up to 3 m thick in places);
- The thickness of the primary aquifer varies from >20 m north of the footprint areas to *c*.2 m along the coast. The saturated thickness of this aquifer also varies across the site as groundwater levels vary between 2 and 20 m below surface;
- The site is located close to the coast and in terms of the hydrogeological cycle, it is near the groundwater discharge zone;
- The interpreted groundwater flow direction is towards the south-east.

In addition, the following detailed specific characteristics and geohydrological conditions apply (based on existing data and information):

- The hydraulic gradient across the site was calculated to be 0.02 in the intergranular Algoa Aquifer and 0.01 in the fractured TMG Aquifer;
- Groundwater flows towards the coast at an estimated rate of between 2 to 3 m/d in the Algoa Aquifer and at <1 m/d in the TMG Aquifer, suggestion a quick migration in the intergranular aquifer;

- The unconfined nature of the sediments means that recharge to the Algoa Aquifer occurs across the entire site. A recharge rate of 10 to 15 per cent of MAP is considered reasonable;
- High borehole yields are common in the Algoa Aquifer especially where the cobble layer is intersected. Yields of up to 10 L/s and higher can be expected within this aquifer;
- High yielding boreholes can also be encountered in the TMG Aquifer.
- Yields up to 5 L/s can be expected in this aquifer especially where the Peninsula Aquifer is intersected;
- Data obtained during the SSR suggests that both the Algoa and TMG aquifers can be developed as potential water supply sources to the proposed plant and surrounding areas;
- Initial indications are that there is limited connectivity between the upper unconfined intergranular aquifer and the deeper lying semi-confined fractured aquifer;
- The southern and western parts of the Langefonteinvlei are perched above the local groundwater table (see **Figure 2.67**, **Figure 2.68** and **Figure 2.69**).



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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
3D CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE THYSPUNT SITE AND SURROUNDS

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Figure 2.67: North-South Cross-Section AB Through Langefonteinvlei, Showing Inferred Surface/ Groundwater Linkages Resulting in Wetland Formation and Function, Thyspunt Site

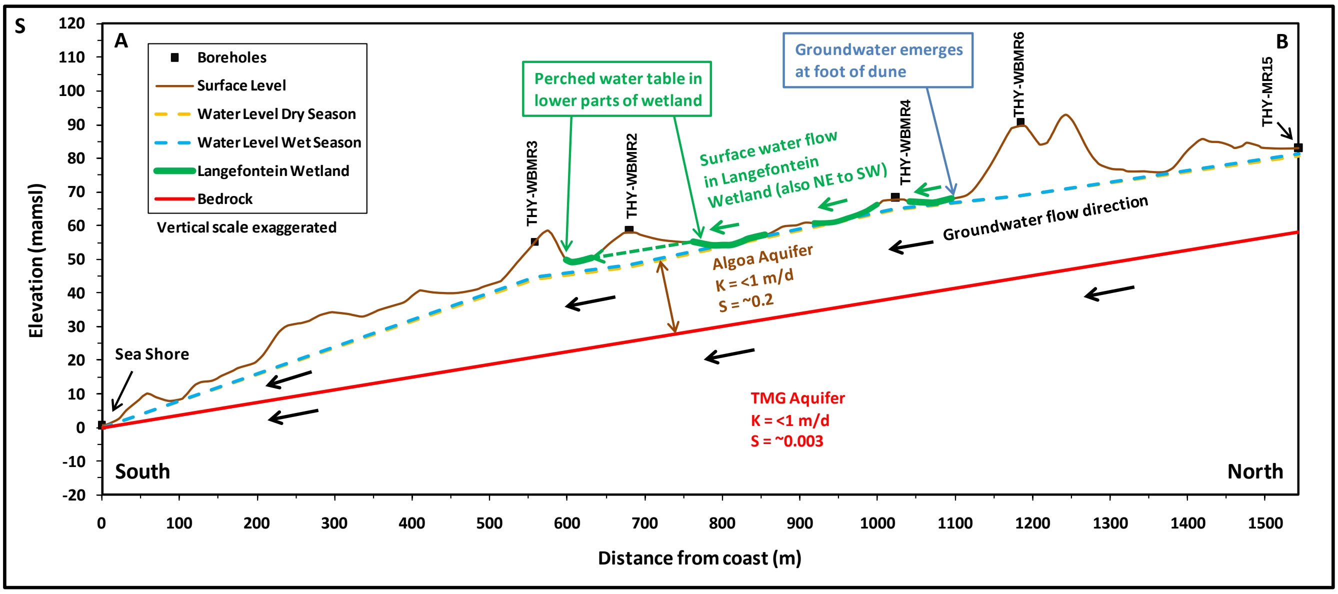


Figure 2.68: North-South Cross-Section CD through Langefonteinvlei, Showing Conceptual Surface/ Groundwater Linkages Resulting in Wetland Formation and Function, Thyspunt Site

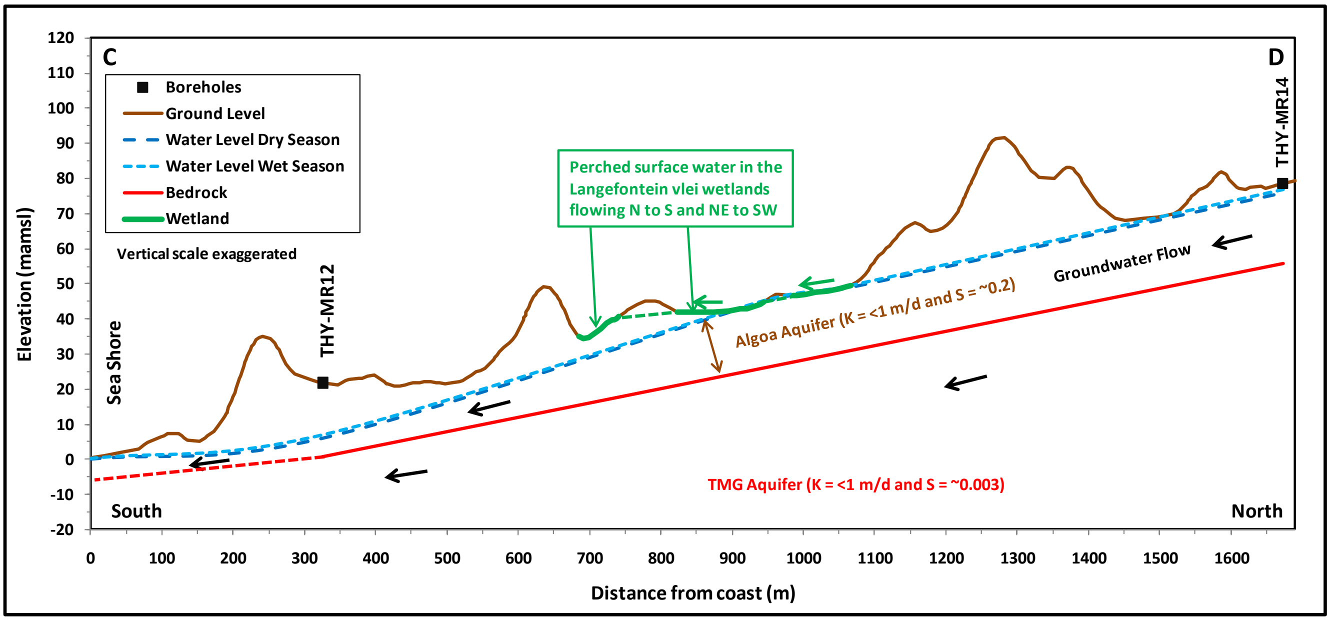
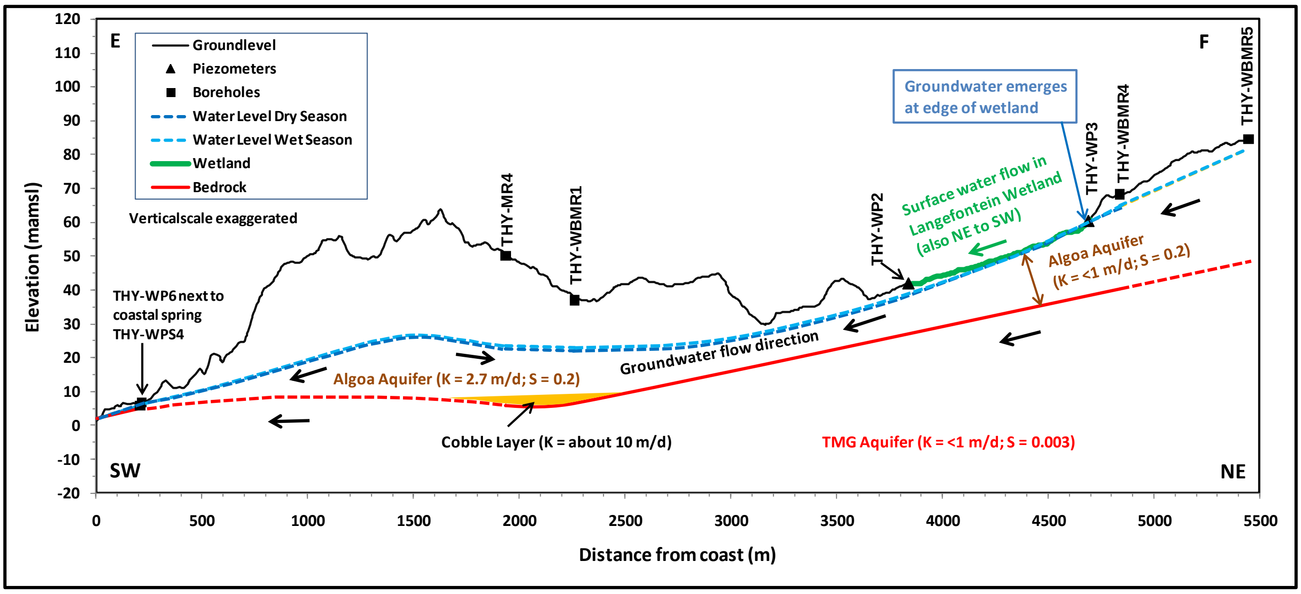


Figure 2.69: Southwest-Northeast Cross-Section EF Through Langefonteinvlei, Showing Conceptual Surface/ Groundwater Linkages Resulting in Wetland Formation and Function, Thyspunt Site



2.3.17 Numerical Modelling

a) REGIONAL MODEL

The regional model covered the whole of quaternary catchment K80F and portions of K90D and K90E up to the Krom River (**Figure 2.70**). The network constructed for the area consists of 401 x 173 cells in the x and y directions, respectively. Each of the cells is 100 x 100 m. The coordinates for the modelled area are -51 600, -3 787 300 (lower left corner) to -11 500, -3 770 000 (upper right corner). The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulated results.

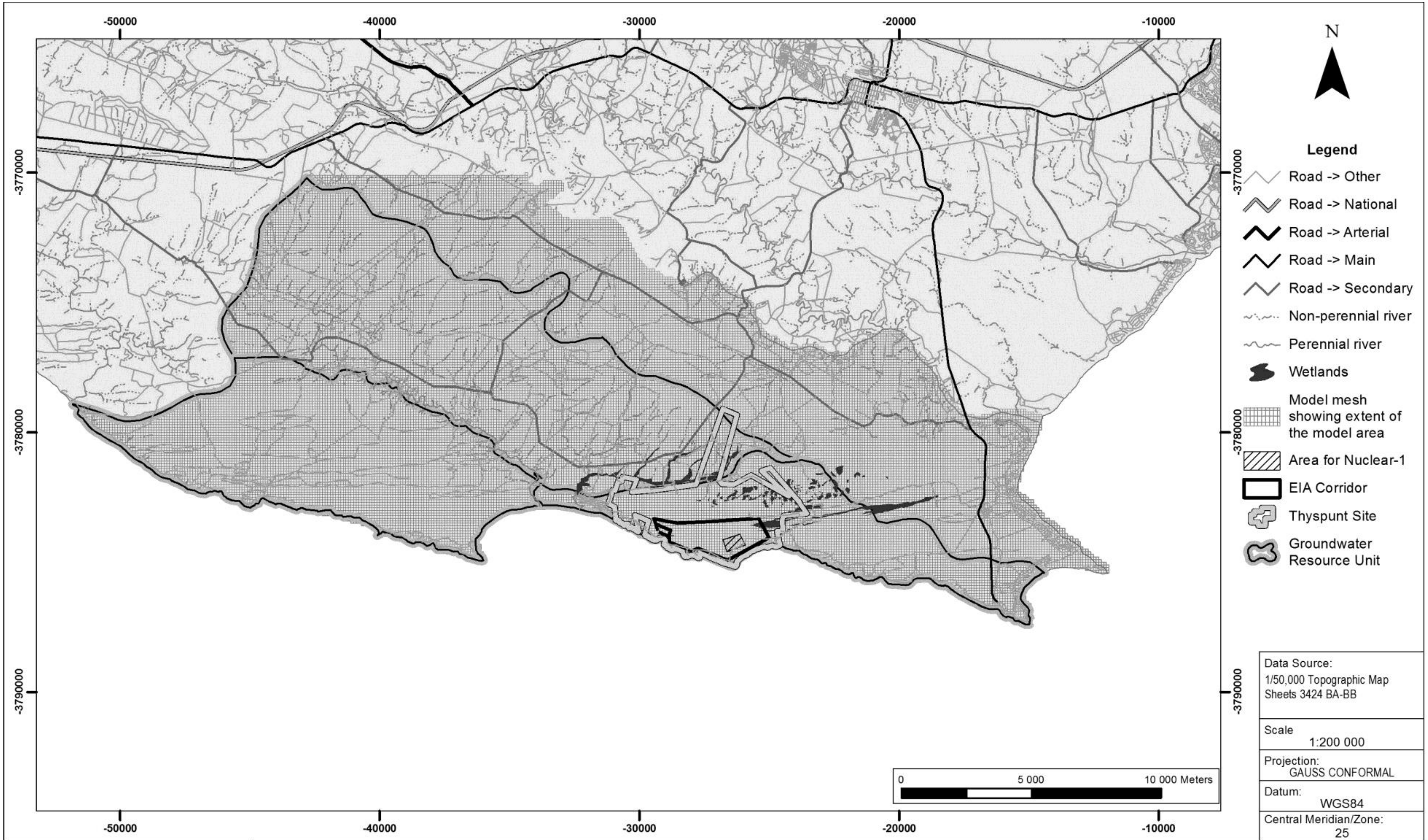
<u>Modelling Software and Solver</u> - *MODFLOW88/96* (Harbaugh and McDonald, 1996) a modular three-dimensional finite difference groundwater flow model which was developed by the U.S. Geological Survey, was the software used during this investigation. It is an internationally accepted and benchmarked modelling package that calculates the solution of the groundwater flow equation using the finite difference approach. The Preconditioned Conjugate-Gradient Solver Package (*PCG2*) is is used to solve the finite difference equations in each step of the *MODFLOW* stress periods.

<u>Boundary conditions</u> - The Indian Ocean was set as a constant head of 0 mamsl. The Krom River was also set as a constant head. All other boundaries were set as no flow boundaries as they coincide with the boundary of the quaternary catchment.

<u>Initial conditions</u> - In order to set up a groundwater flow model for the area, a water level contour map was first generated, as discussed and shown in the section above. Water levels generated were used as initial water levels.

<u>Sources and sinks</u> - The initial groundwater recharge value used in the model is 15 per cent of MAP. Evapotranspiration was set to 0,003 m/d, derived in consultation with the wetlands specialist for Nuclear-1, Dr Liz Day.

<u>Aquifer parameters</u> - Aquifer parameters obtained from analysis of test pumping data for the study area are listed in **Table 2.35**.



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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY

REGIONAL MODEL AREA: THYSPUNT SITE

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Steady state calibration - The steady state head distribution is dependent on recharge, T, 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 T value. The simulated head distribution can then be compared to the measured head distribution and the T or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained. An advantage of a steady state model is that the parameter for S is not required to solve the groundwater flow equation; therefore there are less unknown parameters to determine.

The calibration process was done by changing the model parameters for T and recharge within realistic values. Twenty three boreholes were used to calibrate the steady state groundwater flow model. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads (see **Figure 2.71** and **Figure 2.72**). A square of the Pearson product moment correlation coefficient of 0.84 was achieved, which meets the model calibration criteria of minimum 0.80.

The model mass water balance is shown in Table 2.34 As can be seen, the mass balance percent error is *c*.0.0004 per cent which is within the calibration criteria requirement of <0.5 per cent.

Table 2.34: Thyspunt Regional Steady State Mass Water Balance

	Inflow (m^3/d)	**Outflow (m^3/d)**
Recharge	50 654	0
Sea (Constant Head)	0	31 596
Non-Perennial Drainage Channels	0	3 189
Rivers	979	16 849
Pumping Boreholes	0	0
TOTAL	**51 633**	**51 633**
Mass Balance Percent Error	**-0.0004%**	

Table 2.35: Aquifer Parameters, Thyspunt Site

BH No	Transmissivity T (m^2/d)	Storativity S	Hydraulic Conductivity K (m/d)
Fractured TMG Aquifer			
THY-RP1	1	2.50×10^{-3}	0.02
THY-RP2	298	2.40×10^{-3}	0.45
THY-RP5	30	4.00×10^{-3}	0.43
THY-RP6	29	2.40×10^{-3}	2.34
THY-RP7	7	5.30×10^{-3}	0.67
THY-RP8	16	6.30×10^{-3}	0.17
THY-RP9	3	3.30×10^{-3}	0.15
THY-RP10	2	2.90×10^{-3}	0.04
THY-RP11	11	1.40×10^{-3}	0.97
THY-RP12	7	5.30×10^{-3}	0.36
THY-RP13	0.2	1.50×10^{-3}	0.01

BH No	Transmissivity T (m^2/d)	Storativity S	Hydraulic Conductivity K (m/d)
THY-RP13	10	1.40 x 10^{-3}	0.62
THY-RP14	0.4	4.30 x 10^{-3}	0.03
Algoa (Intergranular) Aquifer			
THY-MR1	3	0.26	1.5
THY-MR2	61	0.22	2.4
THY-MR5	93	0.28	6.6
THY-MR6	222	0.2	14.0

Figure 2.71: Simulated versus Observed Data Sets, Thyspunt Site

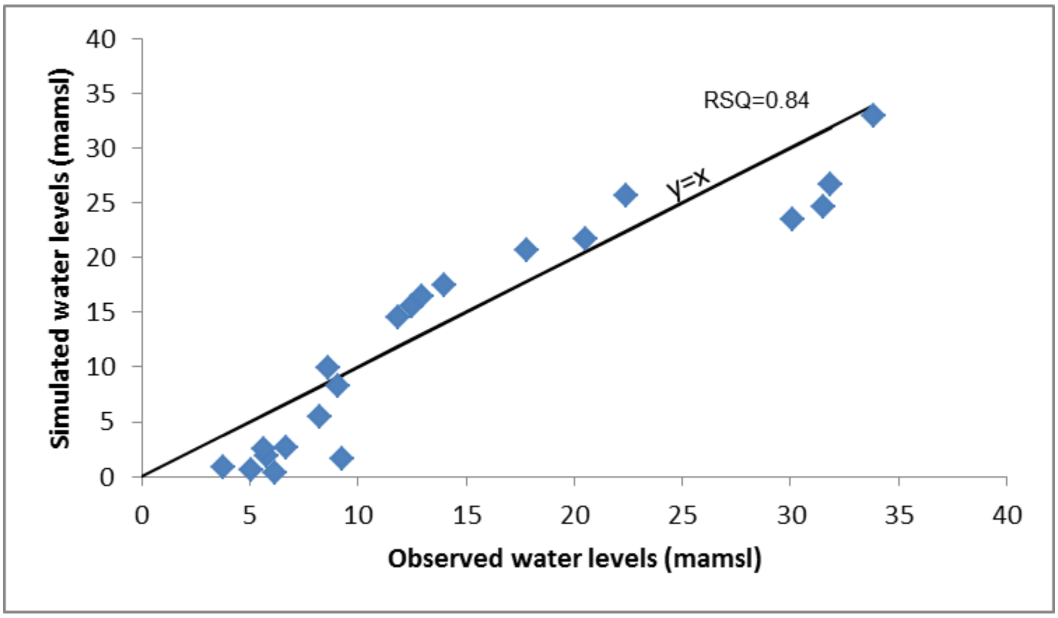
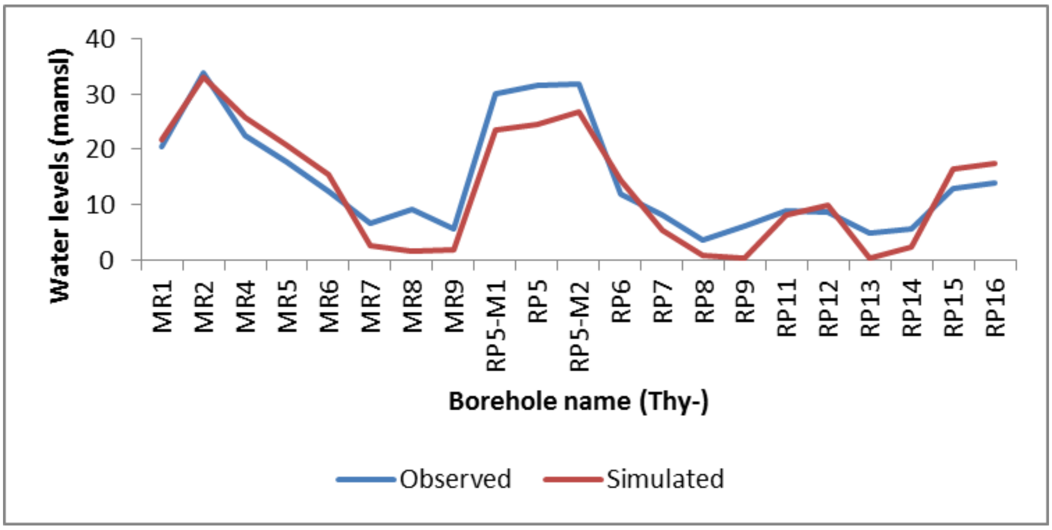


Figure 2.72: Simulated versus Observed Water Levels, Thyspunt Site



The model calibrated best with a transmissivity of 15 m^2/d. The average recharge for the area was adjusted to 10 per cent for best calibration.

It is important to note that as this is a regional model, a geometric mean value for the transmissivities in the sandstones were determined and set for the entire area. Blow yield data and yield data recorded during the hydrocensus were included in this analysis.

In the local model (which includes more detail) discussed in the next section, the above-mentioned values can differ and also differ from some of the test pumping derived T values. However, the modelling is considered to provide a better indication of more regionally applicable T values for predictive purposes.

Transmissivity in an aquifer such as the TMG fractured aquifer varies naturally and it is not possible or necessarily desirable to get consistent values. Variable T values are therefore a function of aquifer anisotropy and heterogeneity and not any flaw in the investigative or analytical methods.

<u>Numerical mass transport model</u>

Input concentrations of contaminants

Input concentrations (non-specific, for illustration purposes) in the model were specified at cells over the areas where contamination could occur e.g. across the areas where air dispersions are likely to be high and the footprint area.

Transmissivities

Transmissivities for the aquifer were specified according to the values obtained during the scenario of the steady state water level calibration (see **Subsection 2.3.4**).

Porosity values

One of the biggest uncertainties encountered during transport modelling of pollutants is the kinematic porosity of the aquifer. A value of 15 per cent was assigned to the modelled area (Spitz and Moreno, 1996).

Longitudinal and transversal dispersivities

A longitudinal dispersivity value of 100 m was selected for the simulations (see **Table D.3** – Field-Scale Dispersivities in Spitz and Moreno, 1996). Bear and Verruijt (1992) estimate that the average transverse dispersivity is 10 to 20 times smaller than the longitudinal dispersivity. An average value of 10 m was selected for this parameter for the simulations.

Hydraulic heads

The hydraulic head values as calculated during the steady simulations were specified in the model.

<u>Scenario using regional model: Potential groundwater contamination due to air pollution from site</u> –

Scenario 1: Deposition of tritium

In this scenario the movement of ^{3}H is simulated from the deposition thereof on the ground, to the movement of it in the groundwater system. Tritium is modelled as though it is conservative, i.e. is not affected by various attenuation processes such as absorption and precipitation. It is once again important to note that the nature of the subsurface (vegetation and soil types present) will also play a role in their movement. Therefore, this scenario can only serve as an indication of what can occur and must be seen as qualitative and not quantitative. Using average annual emissions assuming EPR and AP1000 units to make up the 4 000 MWe it is clear that most of the wetlands and the St. Francis Bay boreholes could be affected by gaseous emissions, but by low concentrations, of *c.*2.5 TU. This is for a 20-year indicative simulation period; 2.5 TUs is equivalent to 0.3 Bq/L. The WHO's limit for drinking water is 10 000 Bq/L.

b) LOCAL MODEL

Generation of finite difference network - For the local model the southern boundary was set as the Indian Ocean, the northern boundary as the quaternary boundary and the western boundary was set as the Slang River (**Figure 2.73**). The model network consists of 250 x 118 cells in the x and y directions, respectively. Each of the cells is 50 x 50 m. The coordinates for the modelled area are -32 500, -3 785 700 (lower left corner) to -20 000, -3 779 800 (upper right corner). In order to include more detail in the model three layers were included, which are:

- Layer 1: Intergranular primary aquifer;
- Layer 2: Intergranular primary aquifer with cobbles;
- Layer 3: Fractured secondary aquifer.

The southern boundary of the site is initially set as a constant head boundary of 0 mamsl. All other boundaries were set as no flow boundaries, except for the Slang River, which was also set as a constant head.

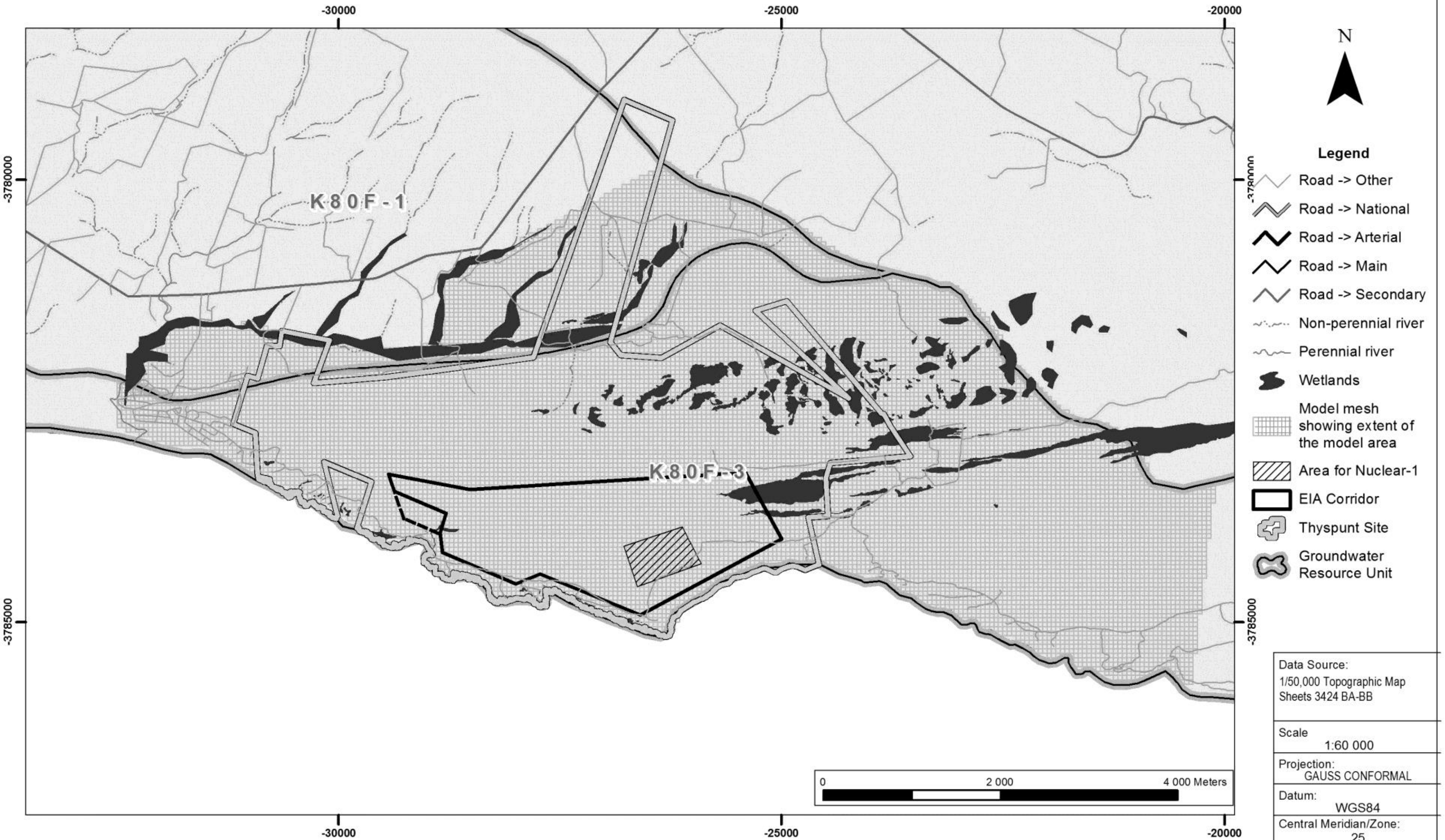
Initial conditions - The initial water levels were once again used as initial conditions in this model.

Sources and sinks - The initial groundwater recharge values are estimated at 10 per cent.

Aquifer parameters - The initial aquifer parameters used in the model are listed in **Table 2.36**.

Table 2.36: Aquifer Parameters, Thyspunt Site

Aquifer Type	Transmissivity (m^2/d)	Storativity	Vertical Hydraulic Conductivity (m/d)
Layer 1	25	1.5×10^{-1}	1
Layer 2	120	1.5×10^{-1}	10
Layer 3	5	1×10^{-3}	0.03



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1/50,000 Topographic Map Sheets 3424 BA-BB

Scale 1:60 000

Projection: GAUSS CONFORMAL

Datum: WGS84

Central Meridian/Zone: 25

Date:	Compiled by:
31 10 2012	GOES/FUBM
Project No.	Fig No.
378677	2.73

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY

LOCAL MODEL AREA: THYSPUNT SITE

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Calibration of the steady state flow model - The results of the steady state simulation are shown in **Figure 2.74** and **Figure 2.75**.

Figure 2.74: Simulated versus Observed Data, Thyspunt Site

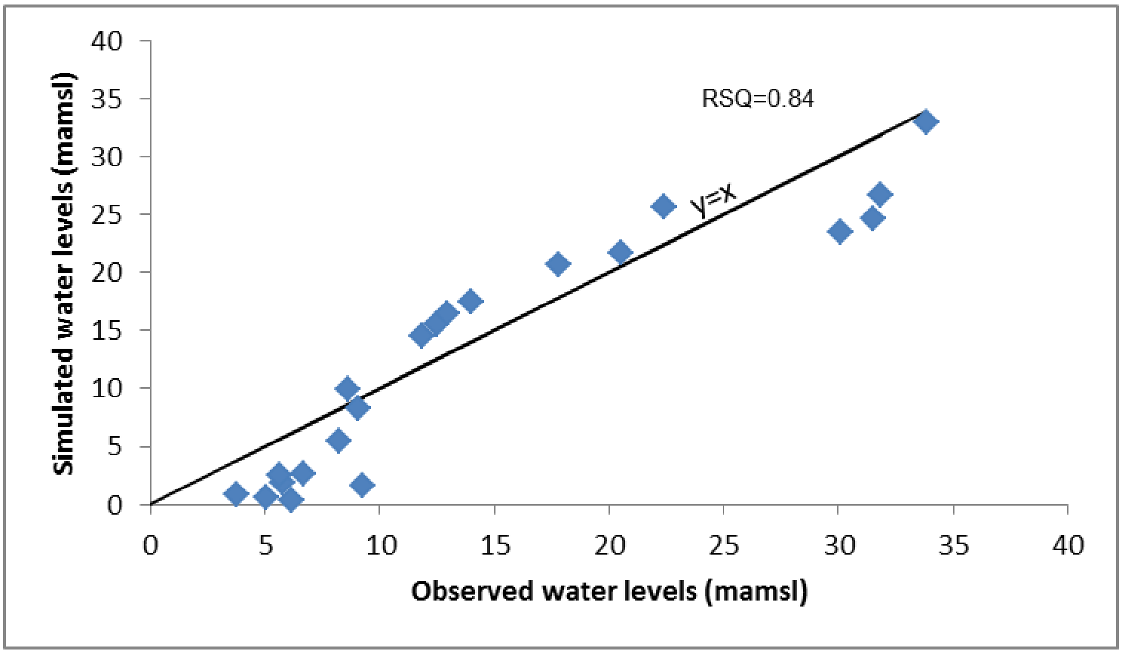
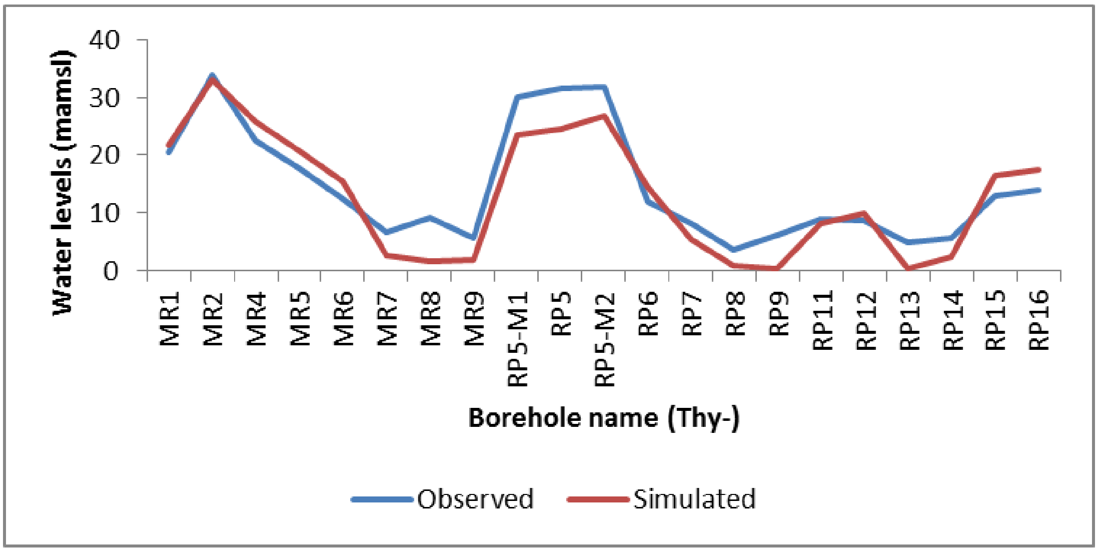


Figure 2.75: Simulated versus Observed Water Levels, Thyspunt Site



The average recharge for the area was set at 10 per cent, with a recharge of 25 per cent being set specifically for non-vegetated dunes.

Sensitivity of the model - Together with the calibration, a sensitivity analysis was run on the model. The model is most sensitive to T values in the three layers of the numerical model. Vertical hydraulic conductivity is the second most sensitive parameter. Very little information is available concerning this parameter.

Numerical mass transport model - The numerical mass transport model was set up with the same parameters as documented under the regional model.

Scenarios using local model - Once the model was been calibrated predictive scenarios were run to assess the impacts of various activities on site on the groundwater system. These activities include dewatering and the movement of potential contamination. It is important to note that these scenarios are hypothetical but will give a reasonable indication of what could happen on site.

Scenario 1: Dewatering the entire provisional 'footprint' without cut-off walls

In this scenario the entire provisional footprint is dewatered to simulate excavation of foundations for the NPS. The zone of depression is shown in **Figure 2.76**.

It is indicated that there will be a maximum of a 0.5 m drop in water levels on the western side of the Langefonteinvlei. However, based on the boreholes drilled for the wetlands monitoring and the geohydrological cross-sections it is evident that the water in the humic layer in the lower southern and south-western parts of the vlei is perched above the groundwater table. Therefore, drawdown in groundwater level in these areas will not have an effect on the Langefonteinvlei.

The water level in the wetlands to the north of the footprint can be affected by up to 1.5 m due to dewatering. This is assuming that they have a direct connection with the underlying groundwater system.

Dewatering of excavations for the NPS will not have any effect on the existing St. Francis Bay wellfields, the existing groundwater supplies to Oyster Bay or springs supplying the Rebelsrus area.

The expected inflows into a foundation excavation with depth are shown in **Table 2.37**.

Table 2.37: Scenario 1 Expected Inflows, Thyspunt Site

Depth (mbgl)	Inflow (m^3/d)
10	2 000
20	2 300

In this case the maximum drop in groundwater level in the vicinity of the wetlands is 1 to 2 m. The zone of depression is contained within the site and is a worst case scenario that is unlikely to occur.

Scenario 2: Dewatering the entire provisional 'footprint' with cut-off walls

In this scenario a 95 per cent impermeable cut-off barrier was inserted in all layers of the model surrounding the footprint. The length of the barrier is correctly defined by the site boundary, however, the modelled width of the barrier is 50 m, as defined by the model cell size. This will not have a major impact on flow directions and modelled drawdowns, however, as the barrier will still act as a flow impeder in the same orientation. This would correspond to a Nuclear-1 size NPS installation. The simulated zone of drawdown is significantly smaller and no wetlands are impacted, as can be seen in **Figure 2.77**. The expected inflows with depth are listed in **Table 2.38**.

Table 2.38: Scenario 2 Expected Inflows, Thyspunt Site

Depth (mbgl)	Inflow (m^3/d)
10	1 500
20	1 900

The zone of depression is contained within the site and no wetlands are affected. By including an impermeable cut-off wall (in the first 2 layers[2] of the model) upstream of the footprint, the maximum inflow is reduced to 750 m^3/d. The zone of depression is significantly smaller and no wetlands are impacted, as can be seen in **Figure 2.77**. This is the more likely scenario for dewatering.

There will be an impact on groundwater equilibrium when dewatering/ groundwater control measures are implemented for excavation of the foundations for the NPS. These control measures could include cut-off walls and pumping boreholes/wells. They will result in local drawdown of the water table in the short-term but equilibrium will be restored outside of the NPS footprint area with time. Managed artificial recharge could be employed to assist with restoring the *status quo*, with pumped groundwater being fed back into the aquifer.

Scenario 3: Impact of increase in seawater level on the groundwater system

The sea level is raised by 1.2 m in this scenario, based on predictions contained in the Intergovernmental Panel on climate change report (*op cit*). The resultant increase in groundwater levels are shown in **Figure 2.78**. The increase in groundwater level is a maximum of 1.2 m at the coast decreasing to 0.2 at the inland extremity of the illustrative footprint and can easily be taken account of in any groundwater control/management system. These simulations will be updated as necessary with any increases in predicted rise in sea level due to global warming and should likewise be controllable within the groundwater management system designed.

Scenario 4: Potential for seawater intrusion

In this scenario the potential of seawater intrusion is investigated under the influence of dewatering of foundations. As *PMWIN* is not ideal for simulating seawater intrusion, it can only provide a qualitative indication of the possibility of such intrusion. *PMPATH* is included in the *PMWIN* package. This add-on package simulates the advective transport of particles within an aquifer system. Particles were introduced at the coastline and tracked with time. The results indicate that seawater intrusion could occur in a zone of 280 m along the coastline in the vicinity of the footprint (**Figure 2.79**). No identified coastal seeps will be influenced. The use of a cut-off wall will lessen the potential for seawater intrusion.

Scenario 5: Impact of increase in seawater level on dewatering

This scenario is a repeat of scenario 1, but with the sea level raised by 1.2 m. The zone of depression is shown in **Figure 2.79**. The expected inflows with depth are listed in **Table 2.39**. However, dewatering is likely to take place before a significant rise in sea level occurs if the site is approved for installation of an NPS.

[2] Layer 1 = sands, layer 2 = cobbles and sands

Table 2.39: Scenario 4 Expected Inflows, Thyspunt Site

Depth (mbgl)	Inflow (m^3/d)
10	2 500
20	2 900

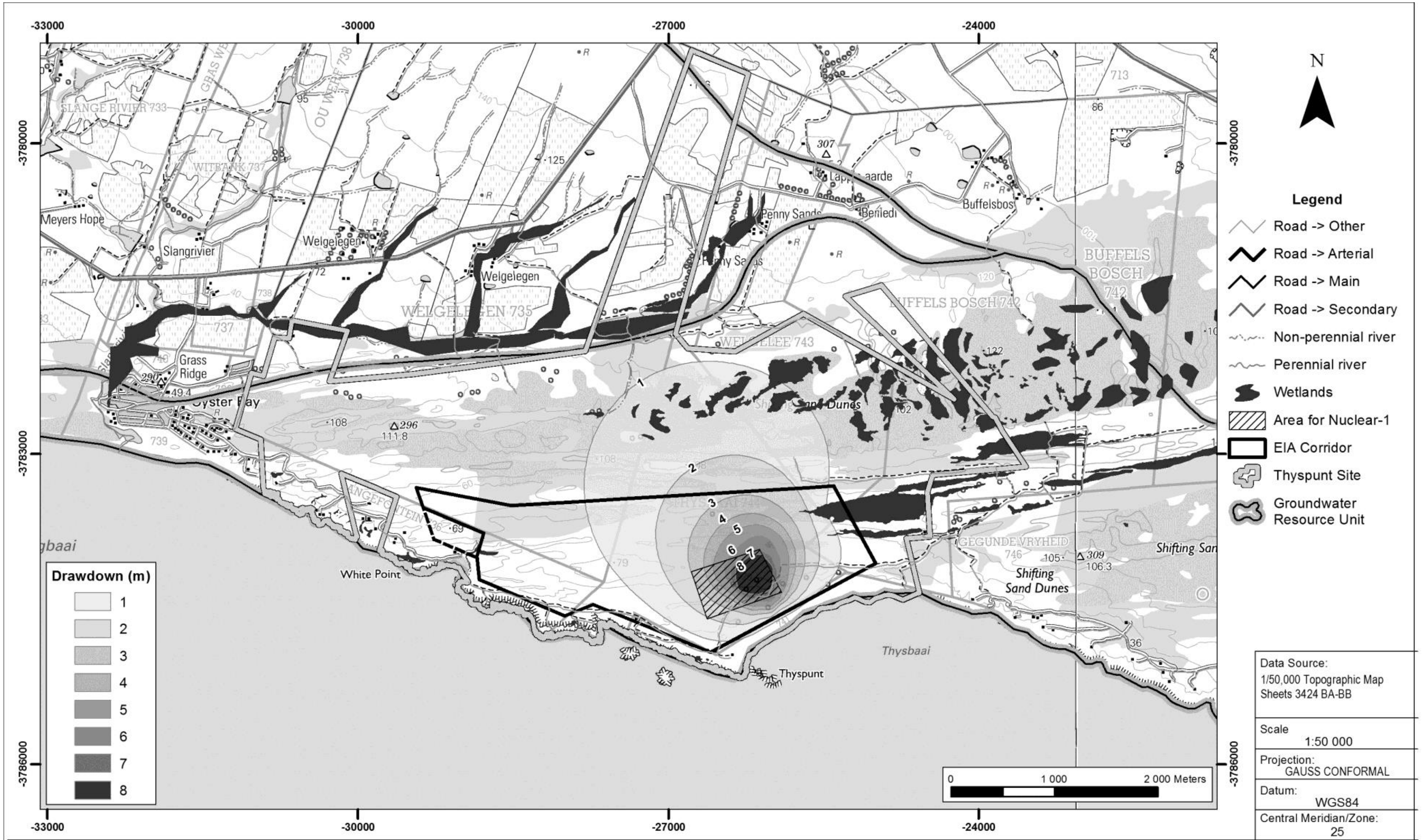
In this case the maximum drop in groundwater level in the vicinity of the wetlands is 1-1.5 m. The zone of depression is contained within the site.

Scenario 6: Groundwater as a potential source of water

The numerical model was used to calculate a water balance for the study area. It is estimated that there is about 2 400 m^3/d (28 L/s) of groundwater available. The suggested position of a supply wellfield has changed based on the additional wetlands/groundwater monitoring results. It is now proposed that if groundwater is to be used for initial site establishment water supply purposes that temporary production boreholes be established to the east and west of the footprint area. The additional wetlands/groundwater monitoring work has shown that the Langefonteinvlei is perched above the water table in its southern and western areas and will not be affected by drawdown in these areas. This part of the site is a Major Aquifer. However, a resource is not a functional resource unless it is used and, with adequate management systems in place, there is no reason not to exploit the local Algoa Aquifer within its sustainable yield bounds, as is already the case elsewhere in the region.

Scenario 7: Potential contamination of the site

In this highly unlikely scenario, potential contamination by liquid effluent from the site is simulated. It is assumed that a hypothetical footprint is 100 per cent contaminated (specific contamination is unspecified at this stage, but non-radiactive). The contamination plume after 50 years is shown in **Figure 2.81**. Most of the contamination moves towards the ocean with time. However, there is a zone of approximately 200 m around the footprint that can become contaminated. The contamination plume is contained in the direct vicinity of the footprint and should not have an influence on any wetlands or water supply boreholes, depending on the final location of the footprint. The area potentially impacted would not be larger for radioactive contaminants. Assuming that an impermeable cut-off wall is installed around the reactor area, this will help contain any liquid contaminants emanating from this source.



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Central Meridian/Zone: 25	
Date: 31 10 2012	Compiled by: GOES/FUBM
Project No. 378677	Fig No. 2.76

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY

ZONE OF DEPRESSION SCENARIO 1 (DRAWDOWN IN M), DEWATERING OF THE ENTIRE PROVISIONAL FOOTPRINT WITHOUT CUT-OFF WALLS: THYSPUNT SITE

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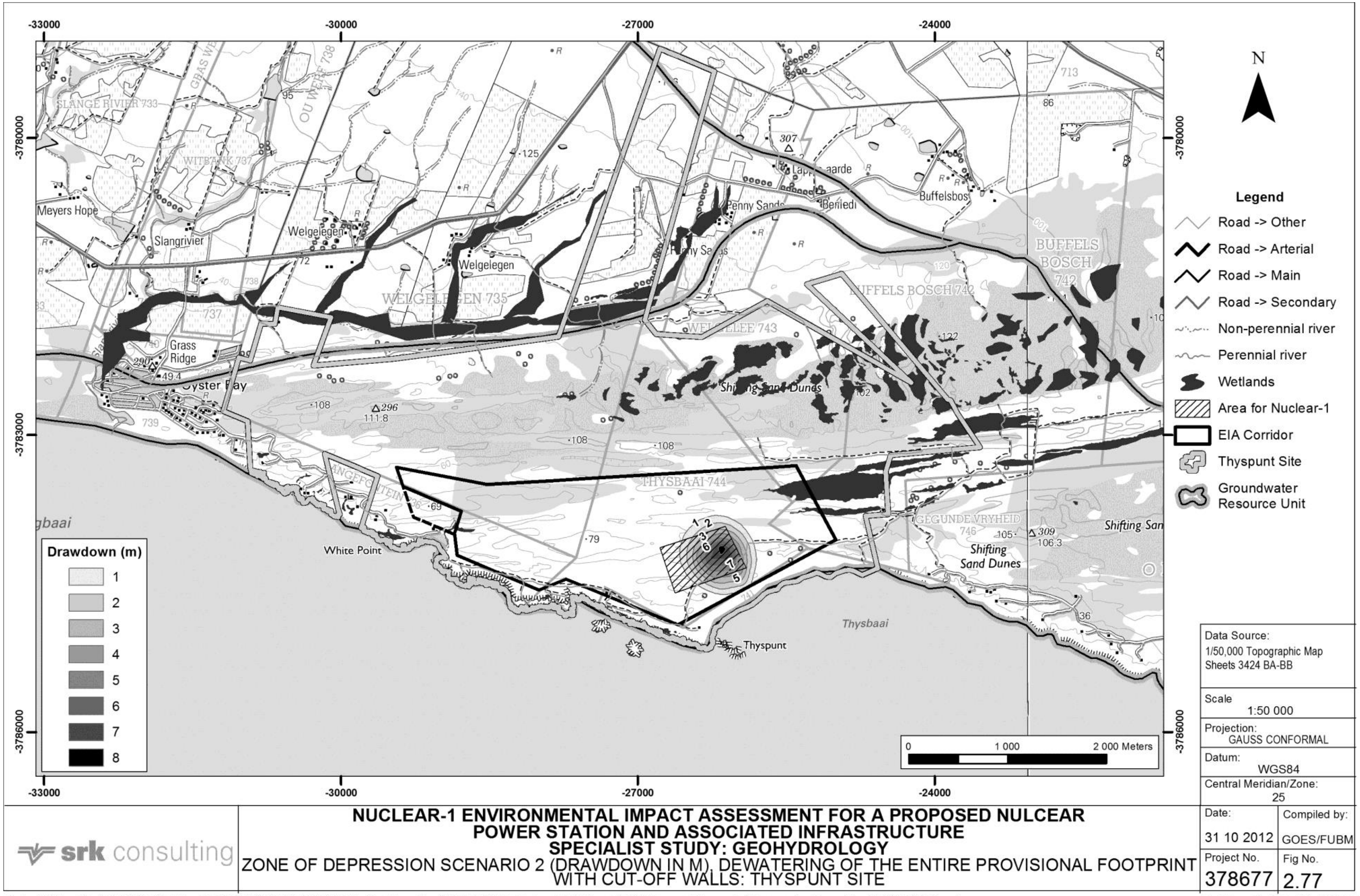
Revision: C Date: 02 12 2014



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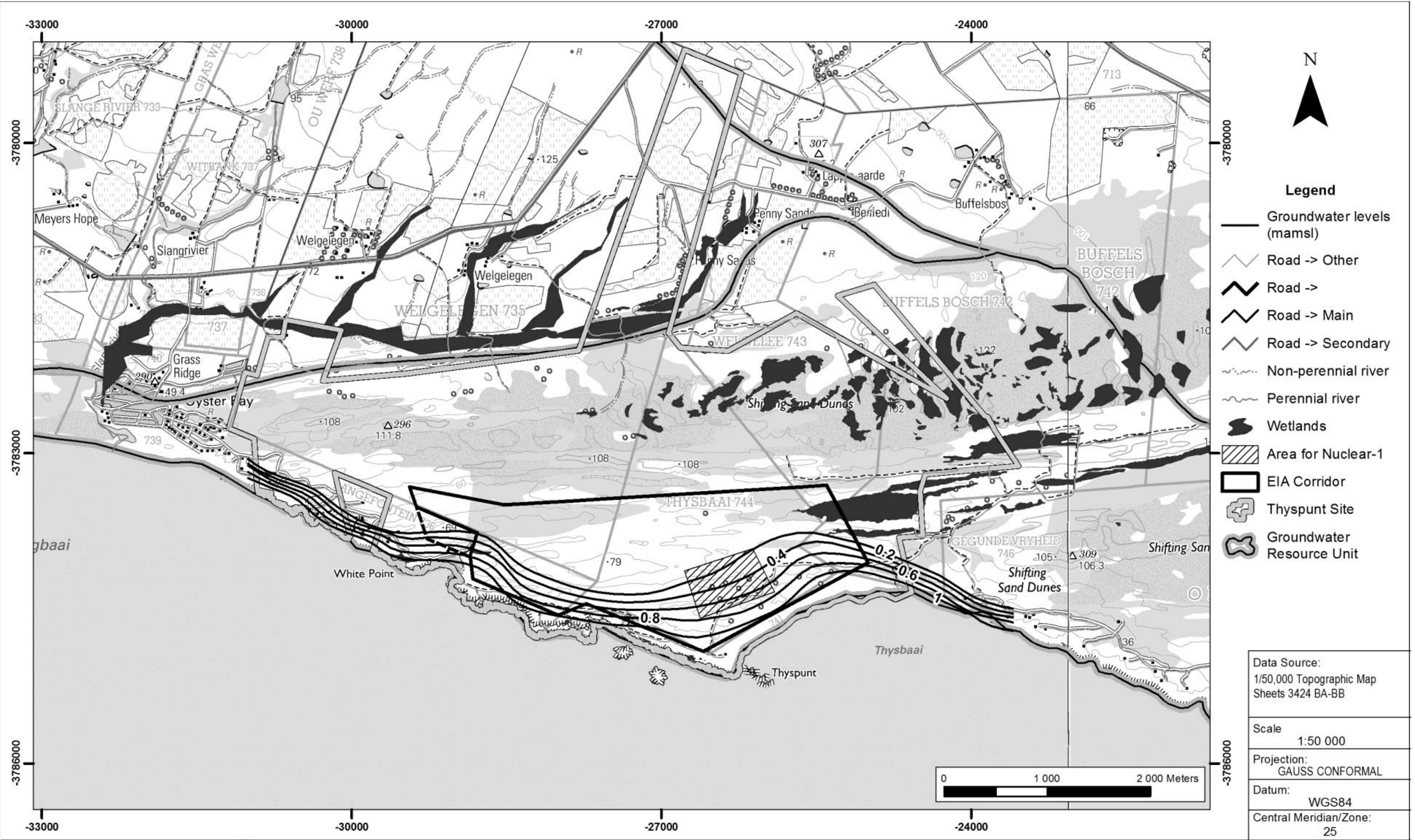
Revision: C Date: 02 12 2014



srk consulting	**NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY** **INCREASE IN GROUNDWATER LEVELS DUE TO INCREASE IN SEA LEVEL**	Date: 31 10 2012	Compiled by: GOES/FUBM
		Project No. 378677	Fig No. 2.78

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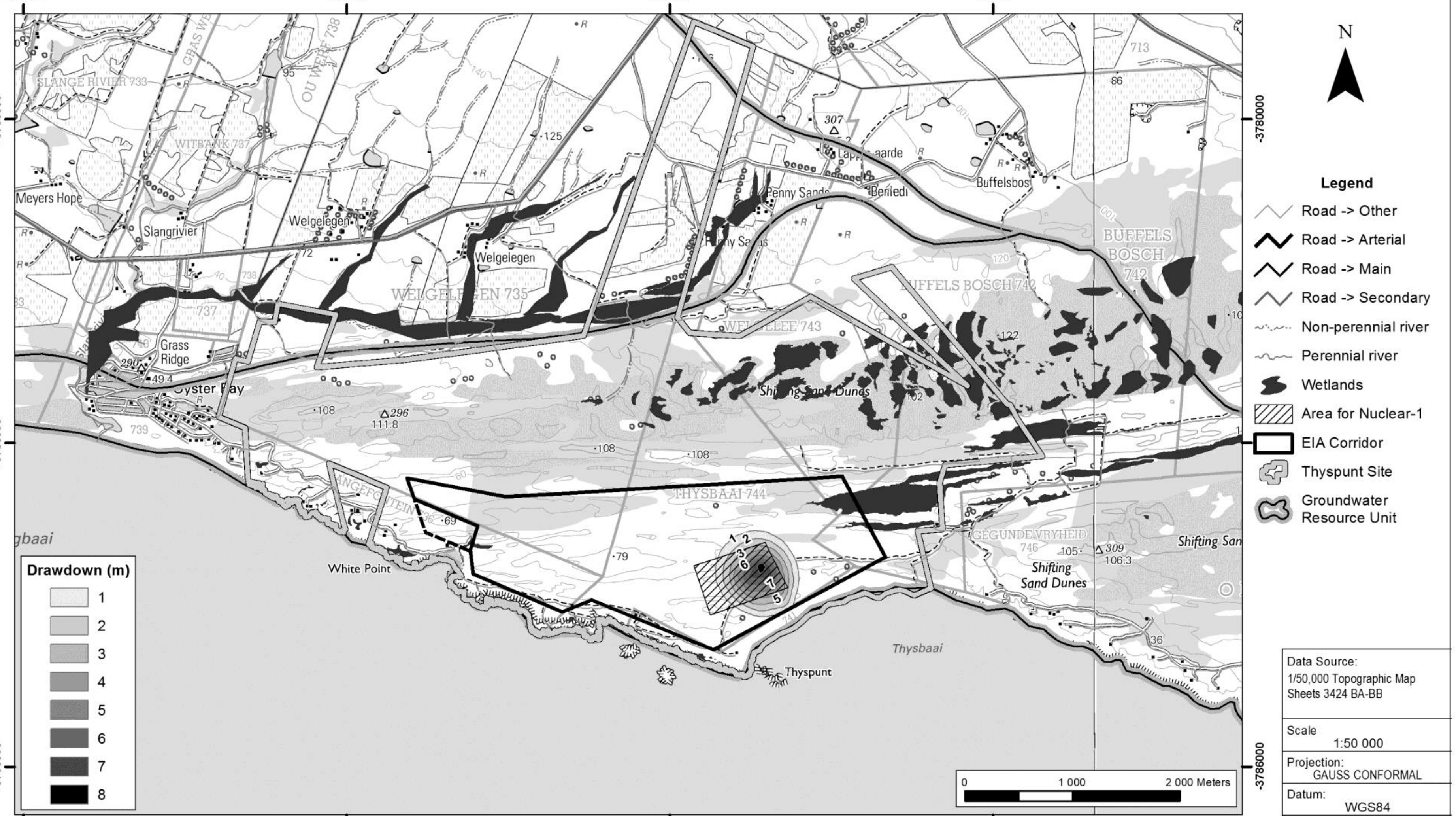
Revision: C Date: 02 12 2014



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Projection: GAUSS CONFORMAL
Datum: WGS84
Central Meridian/Zone: 25

Date: 31 10 2012	Compiled by: GOES/FUBM
Project No. 378677	Fig No. 2.79

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
ZONE OF SEA WATER INTRUSION SCENARIO 4 (DRAWDOWN IN M),
DEWATERING OF THE ENTIRE PROVISIONAL FOOTPRINT WITH CUT-OFF WALLS: THYSPUNT SITE

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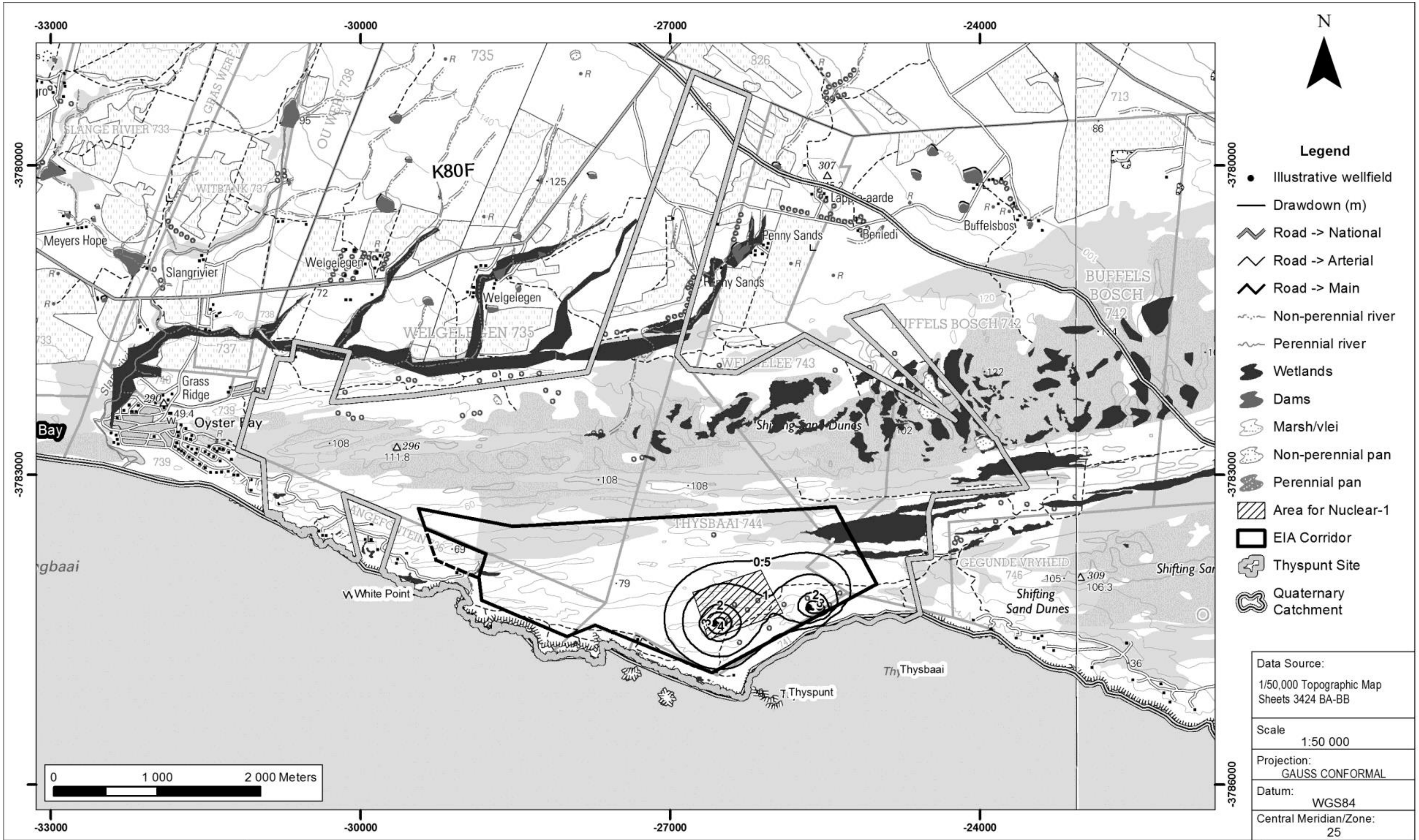
Revision: C Date: 02 12 2014



srk consulting	**NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY**	Date: 31 10 2012	Compiled by: GOES/ FUBM
	TEMPORARY ILLUSTRATIVE WELLFIELD SHOWING DRAWDOWN (IN M): THYSPUNT SITE	Project No. 378677	Fig No. 2.80

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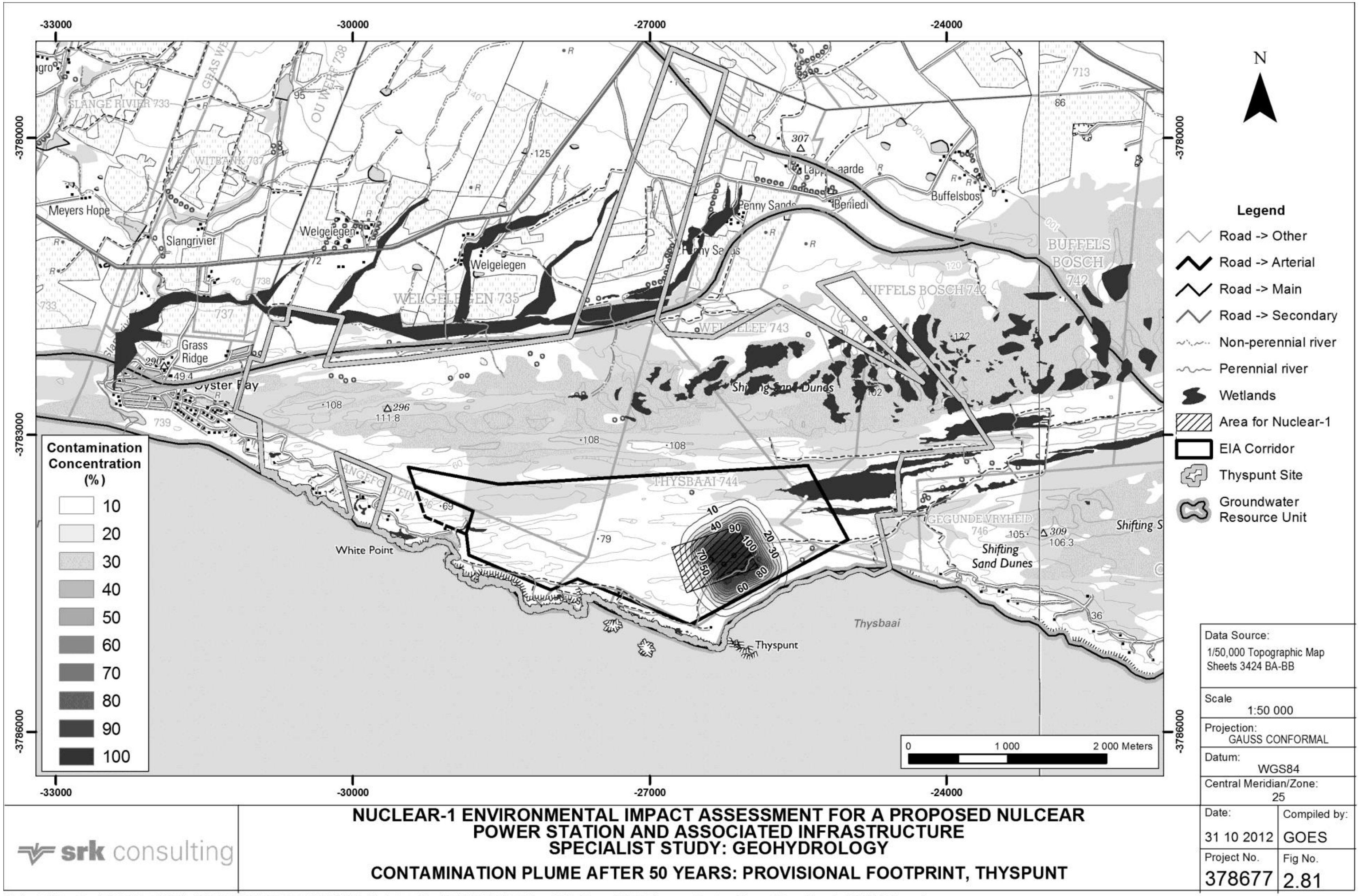
Revision: C Date: 02 12 2014



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Revision: C Date: 02 12 2014

c) LOCAL MODEL FOR WETLAND IMPACT

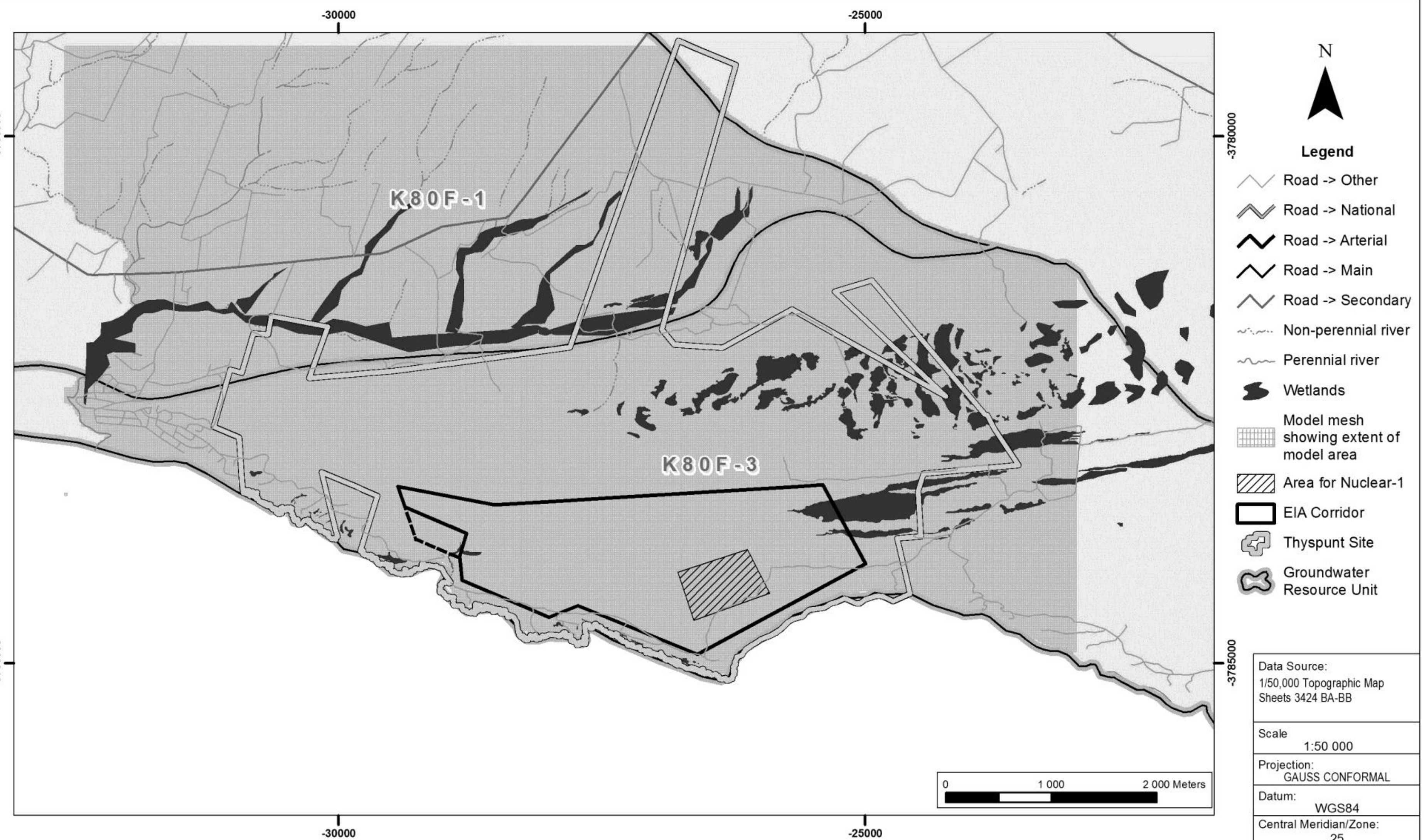
During 2010 the local model was recalibrated with new information obtained from the wetlands monitoring project.

Generation of finite difference network - For this local model the southern boundary was set as the Indian Ocean, the northern boundary as the quaternary catchment boundary and the western boundary was set as the Slang River. The eastern boundary was set on a flow line 2.5 km to the east of the Eskom property (**Figure 2.82**). The model network consists of 640 x 400 cells in the x and y directions, respectively. Each of the cells is 15 x 15 m. The coordinates for the modelled area are -32 600, -3779000 (lower left corner) to -23 000, -3 778 500 (upper right corner). In order to include more detail in the model three layers were included, which are:

- Layer 1: integranular primary aquifer;
- Layer 2: integranular primary aquifer with a humic layer underlying wetlands;
- Layer 3: integranular primary aquifer with cobbles.

The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulated results. Once the network has been set up, all initial and boundary conditions, sources, sinks and aquifer parameters are entered. A steady state calibration is then conducted to ensure that the flow model shows similar behaviour to the actual system under investigation.

Initial conditions - In order to set up a groundwater flow model for the area, 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 where water levels are correlated with altitude. All available levels were plotted against altitude as shown in **Figure 2.83**. The results indicate a correlation of 94 per cent between the data sets. Therefore, Bayesian interpolation is valid and used to calculate water levels for the entire model area. These water levels were used as initial conditions in this model.



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Central Meridian/Zone: 25	
Date: 31 10 2012	Compiled by: GOES/FUBM
Project No. 378677	Fig No. 2.82

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY

LOCAL MODEL AREA: WETLAND IMPACT ASSESSMENT, THYSPUNT SITE

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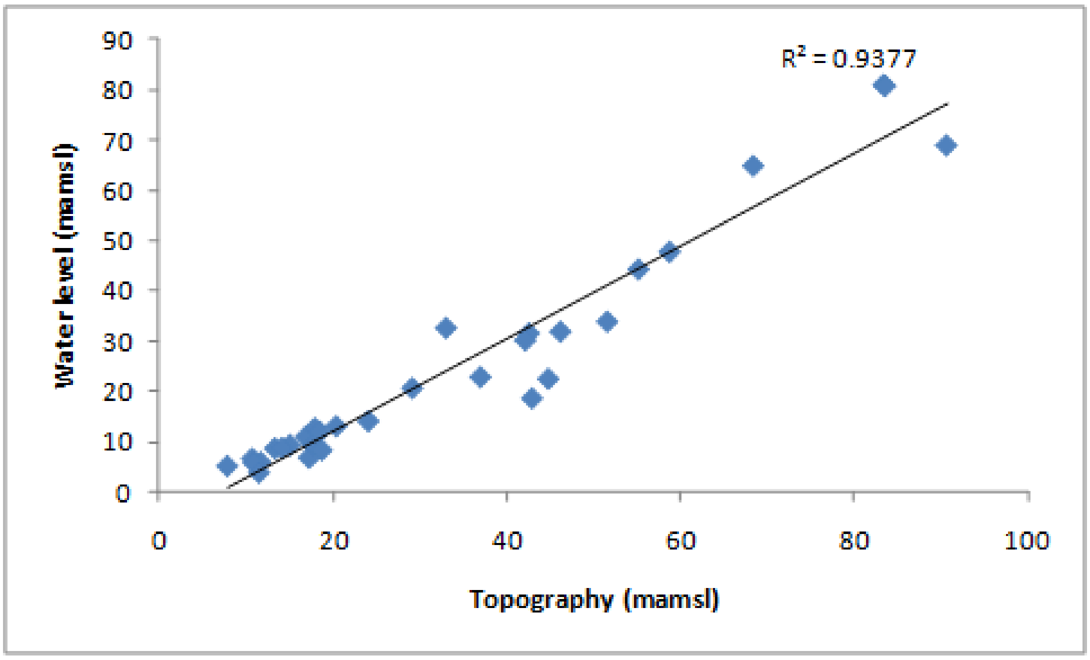
Revision: C Date: 02 12 2014

Figure 2.83: Correlation between Groundwater Levels and Topography



Sources and sinks - The initial groundwater recharge values used in the model are 15 per cent of mean annual precipitation. Evapotranspiration was set to 3.0 x 10^{-3} m/d, derived in consultation with Dr. Liz Day.

Steady State Calibration - The steady state head distribution is dependent on recharge, T, sources, sinks and the 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 transmissivity value. The simulated head distribution can then be compared to the measured head distribution and the transmissivity or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained. An advantage of a steady state model is that the parameter for storativity is not required to solve the groundwater flow equation; therefore there are less unknown parameters to determine. The calibration process was done by changing the model parameters for transmissivity and recharge within realistic values. Thirty boreholes were used to calibrate the steady state groundwater flow model. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads (**Figure 2.84** and **Figure 2.85**). A correlation of 97.8 per cent was achieved.

Figure 2.84: Simulated versus Observed Data, Thyspunt Site Wetland Model

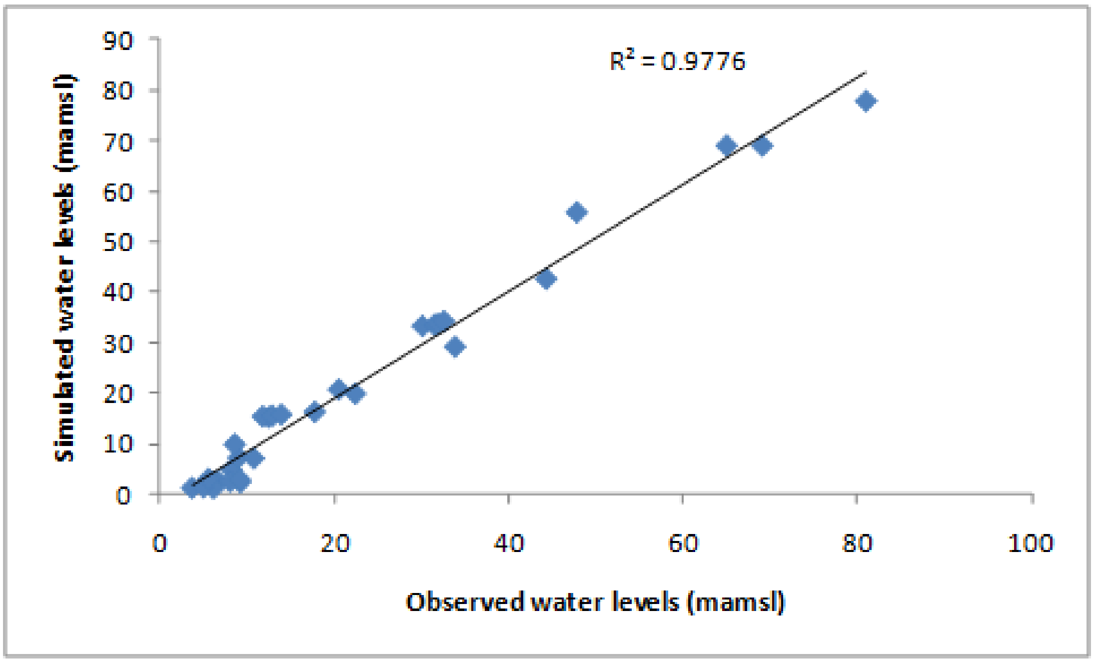
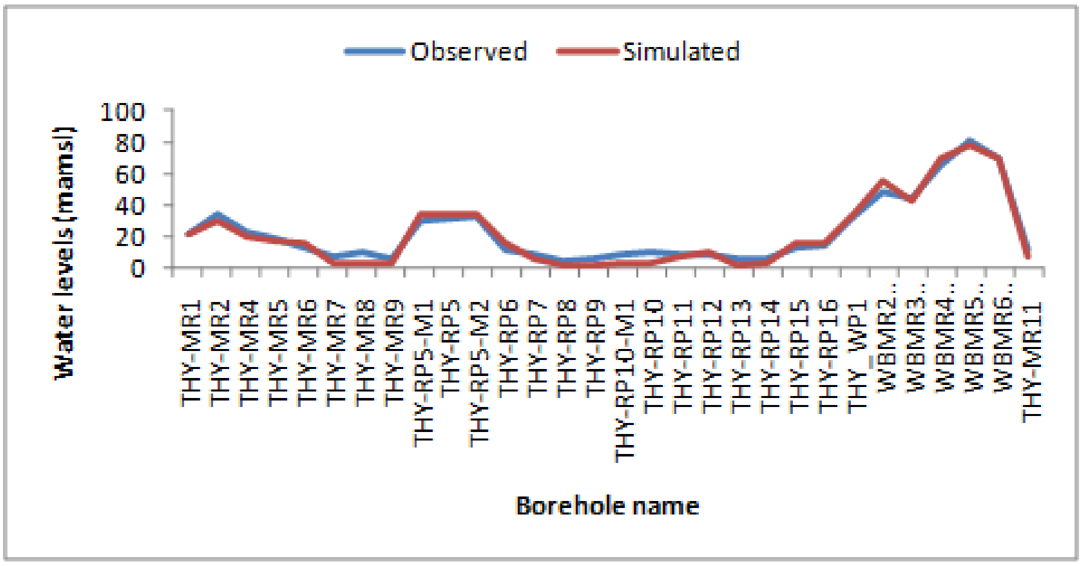


Figure 2.85: Simulated versus Observed Water Levels, Thyspunt Site Wetland Model



The final parameters on which the model calibrated are documented in **Table 2.40**.

Table 2.40: Final Aquifer Parameters used for the Three Layers of the Thyspunt Local Wetland Model

Aquifer type	Transmissivity (m^2/d)	Storativity	Vertical hydraulic conductivity (m/d)
Layer 1	20	1.5×10^{-1}	1
Layer 2	80 (1 where humic layer is present)	1.5×10^{-1} (2.5×10^{-1} where humic layer is present)	5 (1×10^{-3} where humic layer is present)
Layer 3	80 (120 where cobbles are present)	1.5×10^{-1}	5 (10 where cobbles are present)

The average recharge for the area was set at 20 per cent, with an evapotranspiration rate of 1.7×10^{-4} m/d.

Scenario Simulation - Once the model has been calibrated predictive scenarios are run to assess the impacts of various activities on site on the groundwater system, such as dewatering.

Scenario 1: Groundwater flow in the vicinity of wetlands and coastal seeps/springs

In this scenario the groundwater and surface water interaction is considered in the vicinity of the wetlands and the coastal seeps. The groundwater flow is simulated by the numerical model (**Figure 2.86**). The conceptual model for the Langefonteivlei as discussed in **Subsection 2.3.16** together with the associated cross-sections indicates that the groundwater flow in the vicinity of the Langefonteinvlei is towards the southwest and the south. This conceptual model was included in the numerical model.

The wetlands located to the northwest of the site are separated from the footprint area by a water divide and therefore the likelihood of them being influenced by the NPS are less than for the Langefonteinvlei located in the east, and the coastal springs with their associated wetlands.

Groundwater enters the Langefonteinvlei system closest to the proposed position of the NPS to the north and to the east of the wetland. Groundwater leaves the wetland system to the west and south of the system. Under steady state conditions, approximately 30 to 40 L/s (i.e. about 2 600 to 3 500 m^3/day) of groundwater moves through the system. The coastal seeps/springs are formed due to groundwater emerging along the coast at the Algoa/TMG aquifer boundary and from fractures in the TMG Aquifer.

Scenario 2: Dewatering the entire provisional "footprint" without a surrounding cut-off barrier

In this scenario the entire footprint as provided by Eskom in November 2010 is dewatered. The resultant zone of depression is shown in **Figure 2.87**.

It is calculated that there will be a maximum of a 0.5 m drop in water levels on the western side of the Langefonteinvlei. However, based on the boreholes drilled for the wetland monitoring and the geohydrological cross-sections, it is evident that the water in the humic layer in the lower southern and southwestern parts of the vlei is perched above the groundwater table. Therefore, drawdown in water level in these parts will not have an effect on the vlei.

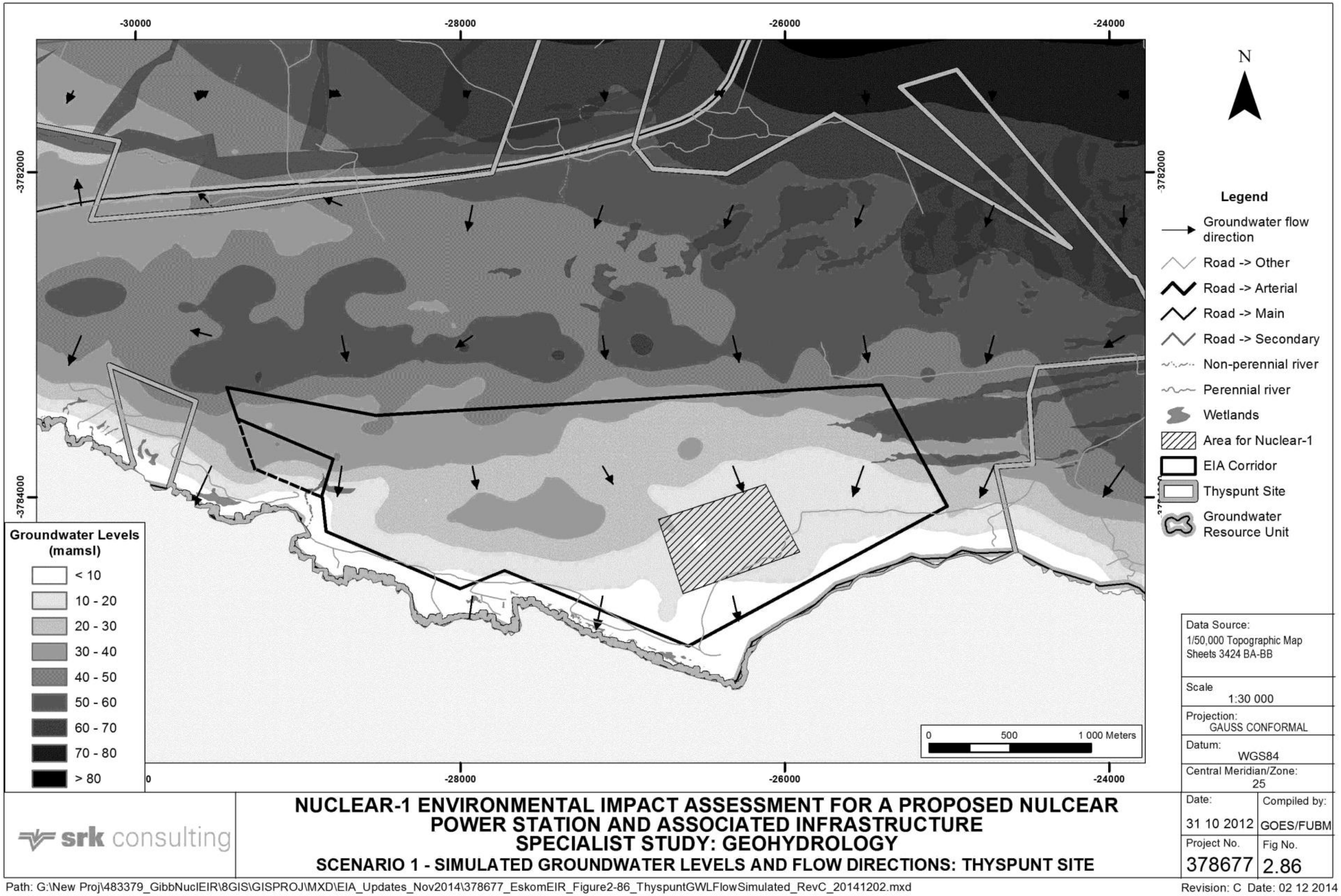
The water level in the wetlands to the north of the footprint can be affected by up to 1.5 m due to dewatering. This is assuming that they have a direct connection with the underlying groundwater system.

Scenario 3: Dewatering the entire provisional footprint with surrounding cut-off walls

In this scenario a 95 per cent impermeable cut-off wall (in all layers of the model) is included around the footprint. The simulated dewatering zone of drawdown is significantly smaller and no wetlands are impacted, as can be seen in **Figure 2.88**.

Scenario 4: Potential seawater intrusion

In this scenario the potential of seawater intrusion is investigated under the influence of
of dewatering of foundations. As *PMWIN* is not ideal for simulating seawater intrusion, it can
intrusion, it can only provide a qualitative indication of the possibility of such intrusion.
PMPATH is included in the *PMWIN* package. This add-on package simulates the advective
advective transport of particles within an aquifer system. Particles were introduced at the
the coastline and tracked with time. The results indicate that seawater intrusion could occur
occur in a zone of 280 m along the coastline in the vicinity of the footprint (**Figure 2.89**
Figure 2.89). No identified coastal seeps will be influenced.



-30000
-28000
-26000
-24000
-3782000
-3784000
N
Legend
Groundwater flow direction
Road -> Other
Road -> Arterial
Road -> Main
Road -> Secondary
Non-perennial river
Perennial river
Wetlands
Area for Nuclear-1
EIA Corridor
Thyspunt Site
Groundwater Resource Unit
Groundwater Levels (mamsl)
< 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
> 80
0 500 1 000 Meters
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Central Meridian/Zone: 25
Date: 31 10 2012
Compiled by: GOES/FUBM
Project No. 378677
Fig No. 2.86
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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
SCENARIO 1 - SIMULATED GROUNDWATER LEVELS AND FLOW DIRECTIONS: THYSPUNT SITE
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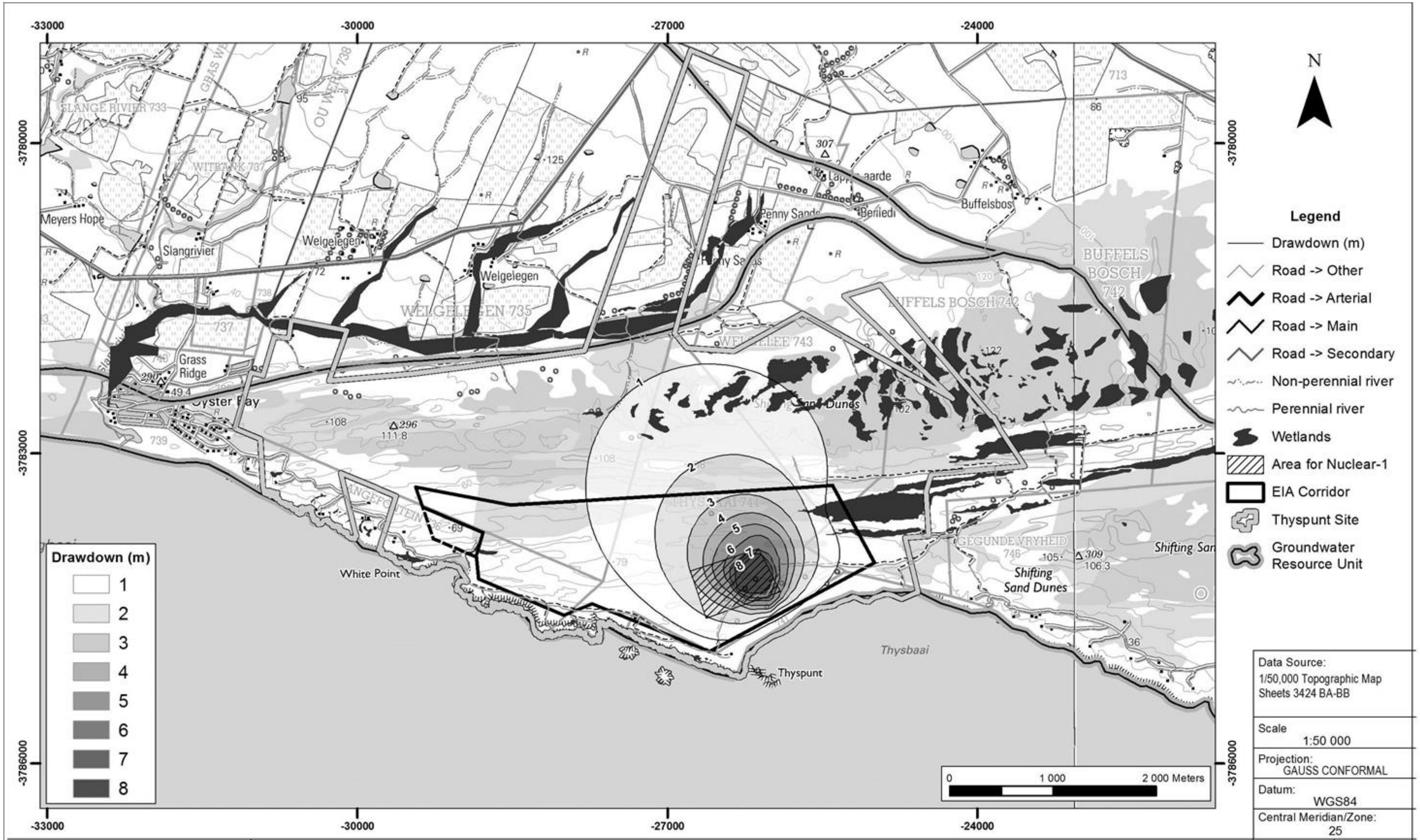

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NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
ZONE OF DEPRESSION SCENARIO 2 (DRAWDOWN IN M), DEWATERING OF THE ENTIRE PROVISIONAL FOOTPRINT WITHOUT CUT-OFF WALLS: THYSPUNT SITE

Date:	Compiled by:
31 10 2012	GOES/FUBM
Project No.	Fig No.
378677	2.87

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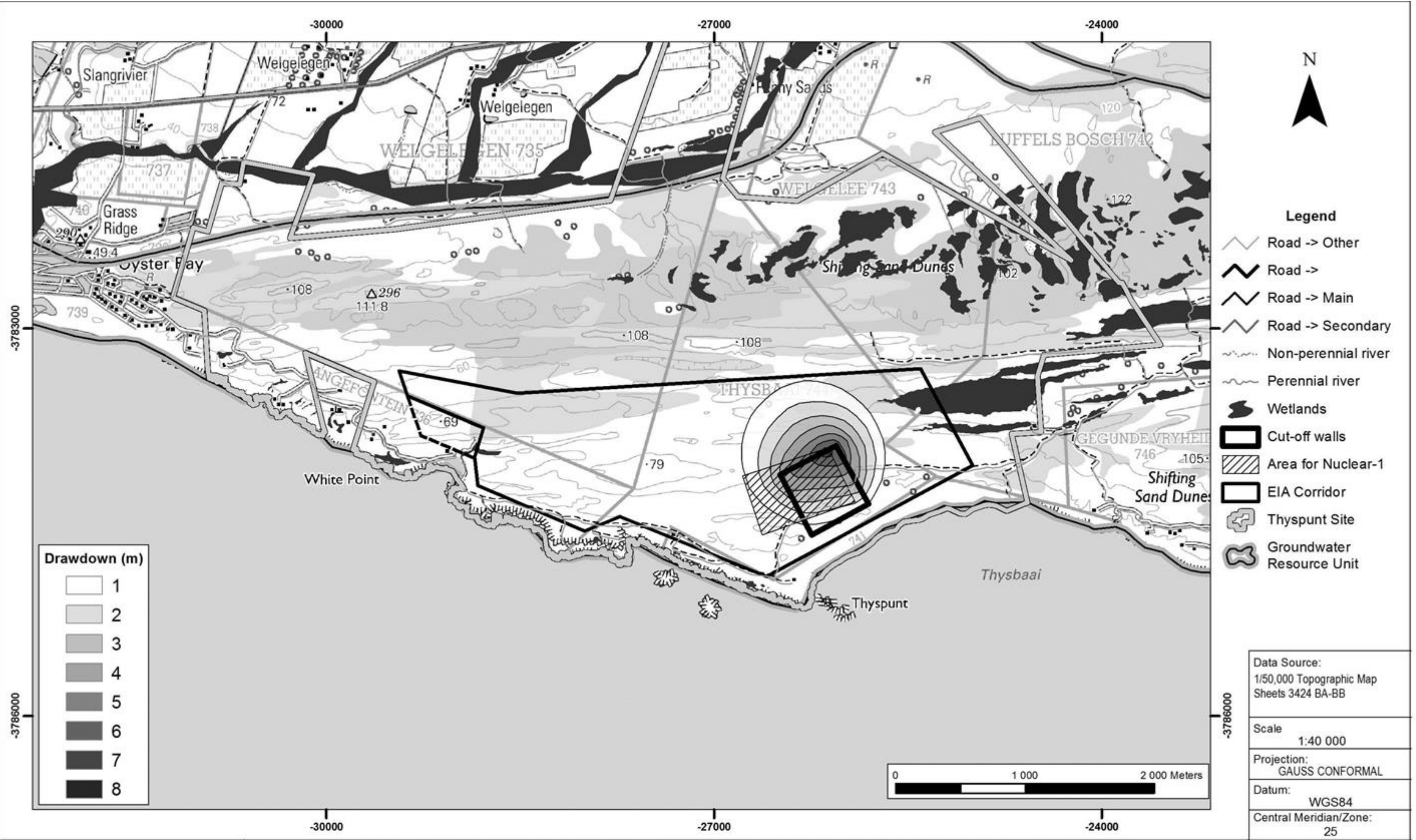

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srk consulting	**NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE SPECIALIST STUDY: GEOHYDROLOGY** ZONE OF DEPRESSION SCENARIO 2 (DRAWDOWN IN M), DEWATERING OF THE ENTIRE PROVISIONAL FOOTPRINT WITH CUT-OFF WALLS: THYSPUNT SITE	Date: 31 10 2012 — Compiled by: GOES/FUBM — Project No. 378677 — Fig No. 2.88

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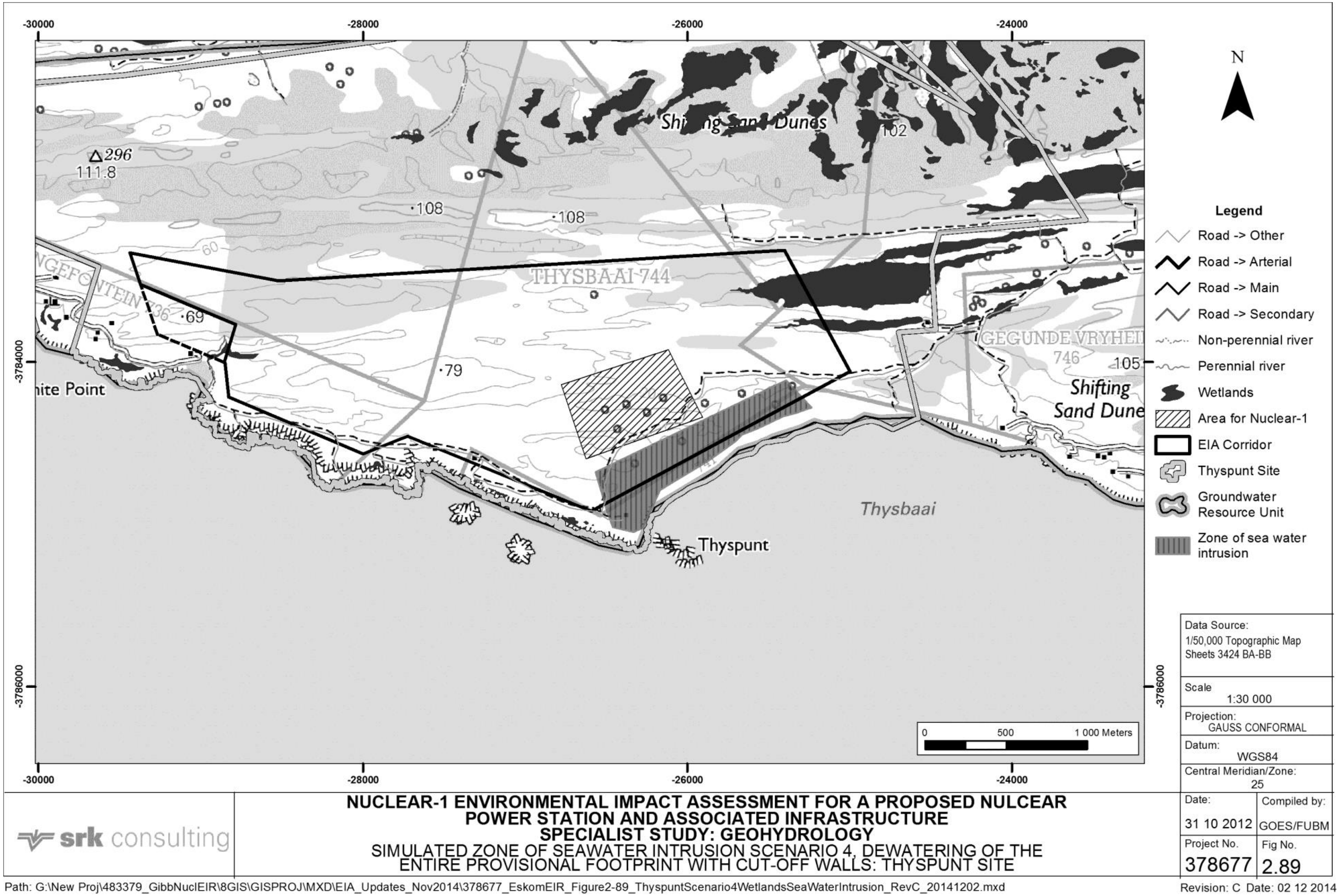
Revision: C Date: 02 12 2014



-30000
-28000
-26000
-24000
-3784000
-3786000
N
Shifting Sand Dunes
102
296
111.8
108
108
60
THYSBAAI 744
69
79
hite Point
GEGUNDE VRYHEID
746
105
Shifting Sand Dune
Thysbaai
Thyspunt
Legend
Road -> Other
Road -> Arterial
Road -> Main
Road -> Secondary
Non-perennial river
Perennial river
Wetlands
Area for Nuclear-1
EIA Corridor
Thyspunt Site
Groundwater Resource Unit
Zone of sea water intrusion
0
500
1 000 Meters
Data Source:
1/50,000 Topographic Map Sheets 3424 BA-BB
Scale
1:30 000
Projection:
GAUSS CONFORMAL
Datum:
WGS84
Central Meridian/Zone:
25
Date:
31 10 2012
Compiled by:
GOES/FUBM
Project No.
378677
Fig No.
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srk consulting
NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NULCEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
SIMULATED ZONE OF SEAWATER INTRUSION SCENARIO 4, DEWATERING OF THE ENTIRE PROVISIONAL FOOTPRINT WITH CUT-OFF WALLS: THYSPUNT SITE
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Revision: C Date: 02 12 2014

c) CONCLUSIONS

The numerical modelling indicates that the zone of depression would extend a maximum of 1.5 km with the dewatering of an entire footprint (unlikely) and 1 km with the dewatering of a third of a footprint (likely) if no mitigation is applied. This zone intercepts some of the wetlands within the vicinity of the proposed footprints, but is restricted to the site.

A very important new conclusion is that the southern portion of the Langefonteinvlei, and the western sections of both the southern and the northern portions of the wetland are perched above the groundwater table of the Algoa Aquifer, rather than being linked directly to it. Drawdown caused by abstraction or dewatering extending to below these parts of the wetland is therefore unlikely to have any effect on wetland hydrology or hydroperiod. However, if drawdown extends to the northern and eastern portions of the wetland (highly unlikely with current footprint and groundwater control measures), the hydrology of the Langefonteinvlei will be affected.

An increase in seawater levels due to global warming will lead to an increase in groundwater levels along the coastline. However, the maximum increase in the groundwater is expected to be <1 m in the footprint area and can be accommodated within any groundwater control system. Seawater intrusion is possible in the vicinity of coastally situated footprints under dewatering conditions but set-back distance from the coast will mitigate this effect.

In the highly unlikely event of NPS liquid emissions entering the groundwater system, they would migrate towards the sea and as such very little groundwater contamination is expected. The proposed cut-off wall will also help to contain such emissions. Gaseous emissions would be dispersed by the prevailing winds but would be at low concentrations from normal operations.

2.4 Site Sensitivity

Site sensitivity has been assessed according to the categories listed below.

Category	Description
High sensitivity	These are no go areas or severely prohibited areas for development; they may be protected by legislation
Medium sensitivity	These are areas that may have the potential for development, if adequate mitigation measures are prescribed
Low sensitivity	These areas have no sensitivity to development

The sensitivity of each of the sites is shown in **Figure 2.90** (Duynefontein), **Figure 2.91** (Bantamsklip) and **Figure 2.92** (Thyspunt) for the defined site areas.

Criteria used for defining site sensitivity were the presence of any of the following:

- Major aquifers (Medium);
- Existing supply boreholes/springs (High);
- 500 m buffer zones around the above (Medium).

2.4.1 Duynefontein

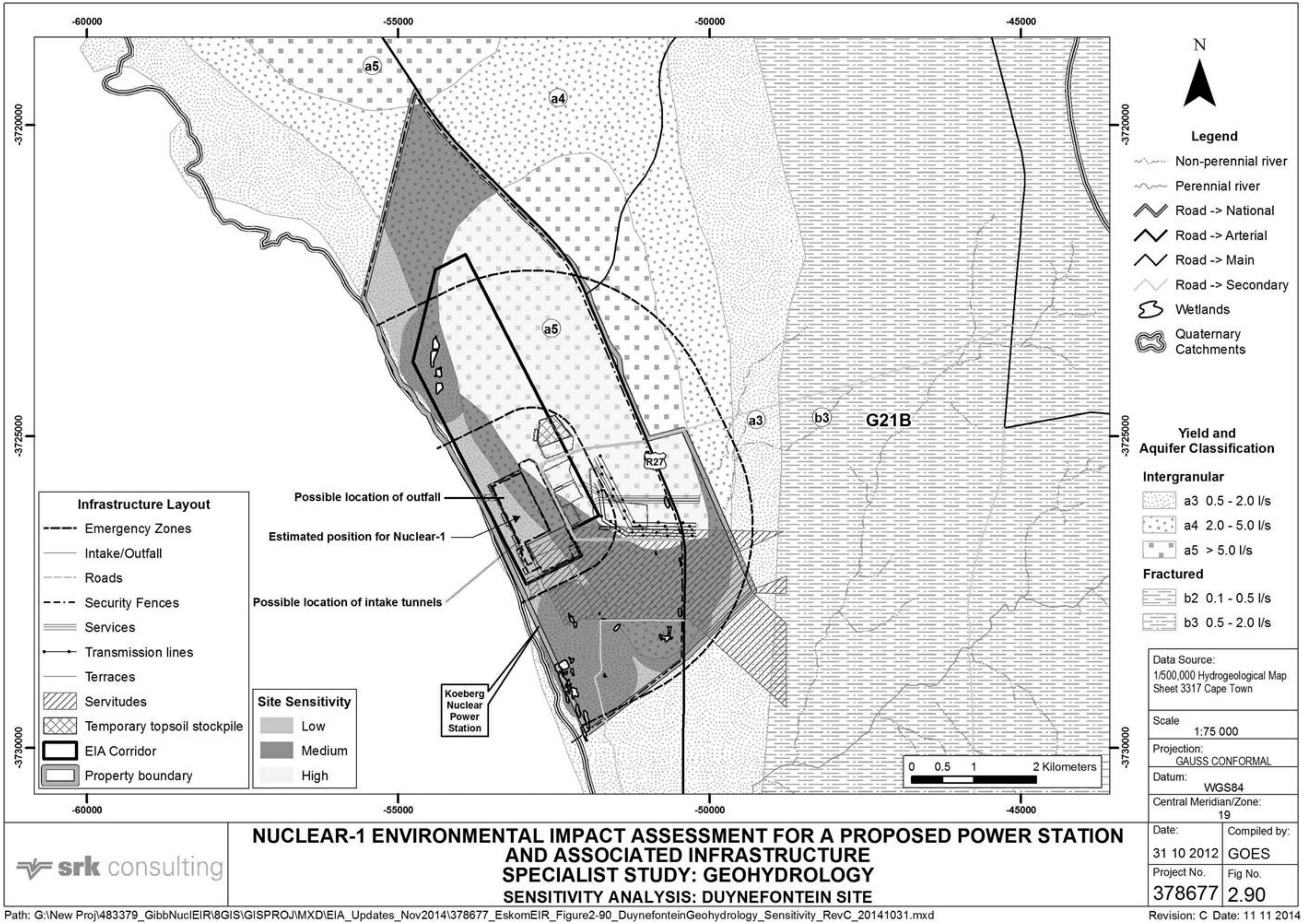
Site sensitivity analysis indicates a mostly low sensitivity along the coast, increasing to high sensitivity further inland, where primary aquifer development increases.

2.4.2 Bantamsklip

Site sensitivity analysis indicates a low sensitivity over the whole site with the exception of a spring in the north.

2.4.3 Thyspunt

Site sensitivity analysis indicates a medium sensitivity over most of the site (excludes wetland areas).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-55000
-50000
-45000
-3720000
-3725000
-3730000
a5
a4
a3
b3
G21B
R27
Possible location of outfall
Estimated position for Nuclear-1
Possible location of intake tunnels
Koeberg Nuclear Power Station
N
Legend
Non-perennial river
Perennial river
Road -> National
Road -> Arterial
Road -> Main
Road -> Secondary
Wetlands
Quaternary Catchments
Yield and Aquifer Classification
Intergranular
a3 0.5 - 2.0 l/s
a4 2.0 - 5.0 l/s
a5 > 5.0 l/s
Fractured
b2 0.1 - 0.5 l/s
b3 0.5 - 2.0 l/s
Infrastructure Layout
Emergency Zones
Intake/Outfall
Roads
Security Fences
Services
Transmission lines
Terraces
Servitudes
Temporary topsoil stockpile
EIA Corridor
Property boundary
Site Sensitivity
Low
Medium
High
0 0.5 1 2 Kilometers
Data Source:
1/500,000 Hydrogeological Map Sheet 3317 Cape Town
Scale 1:75 000
Projection: GAUSS CONFORMAL
Datum: WGS84
Central Meridian/Zone: 19
srk consulting
NUCLEAR-1 ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED POWER STATION AND ASSOCIATED INFRASTRUCTURE
SPECIALIST STUDY: GEOHYDROLOGY
SENSITIVITY ANALYSIS: DUYNEFONTEIN SITE
Date: 31 10 2012
Compiled by: GOES
Project No. 378677
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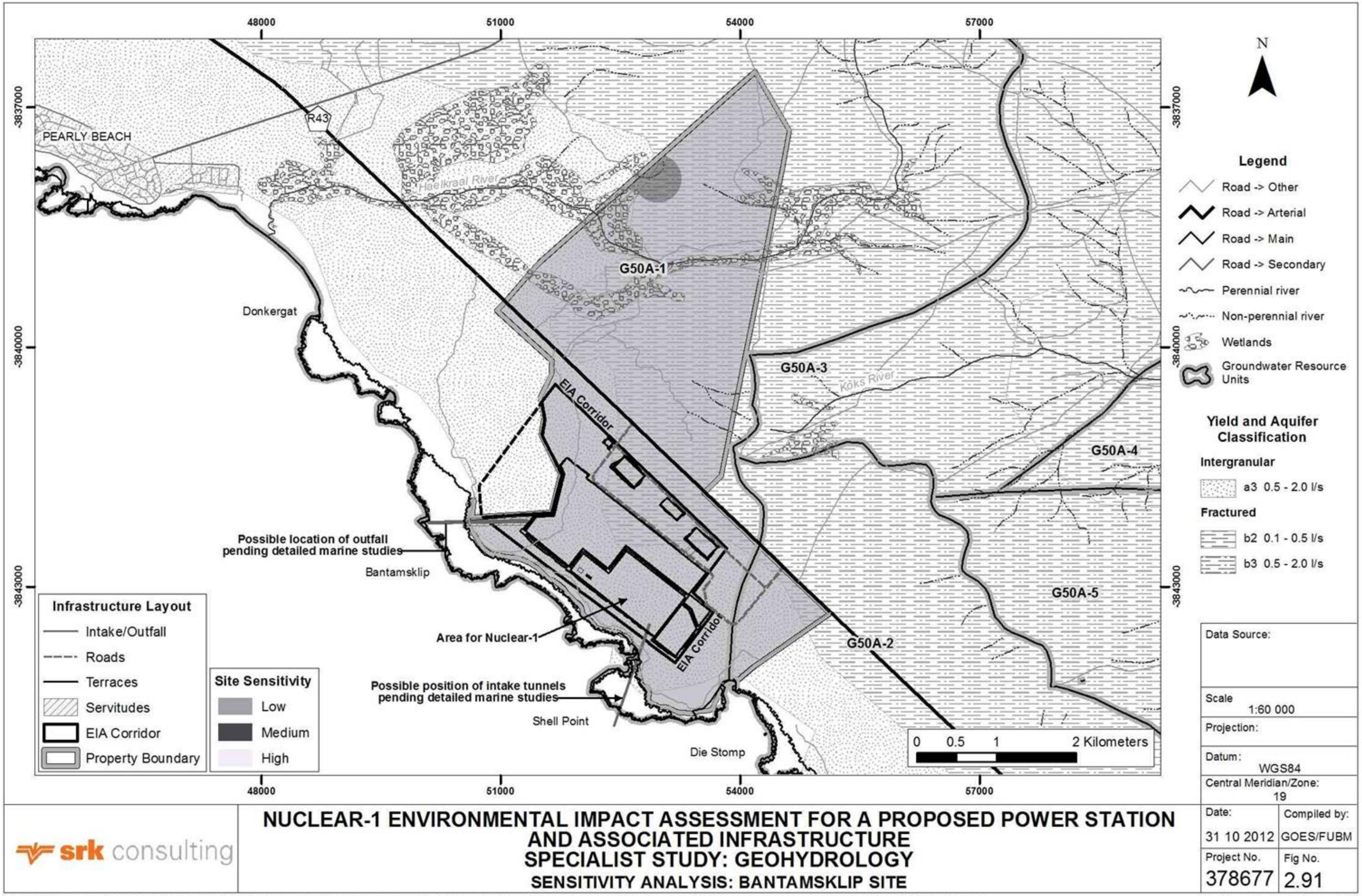
Revision: C Date: 11 11 2014



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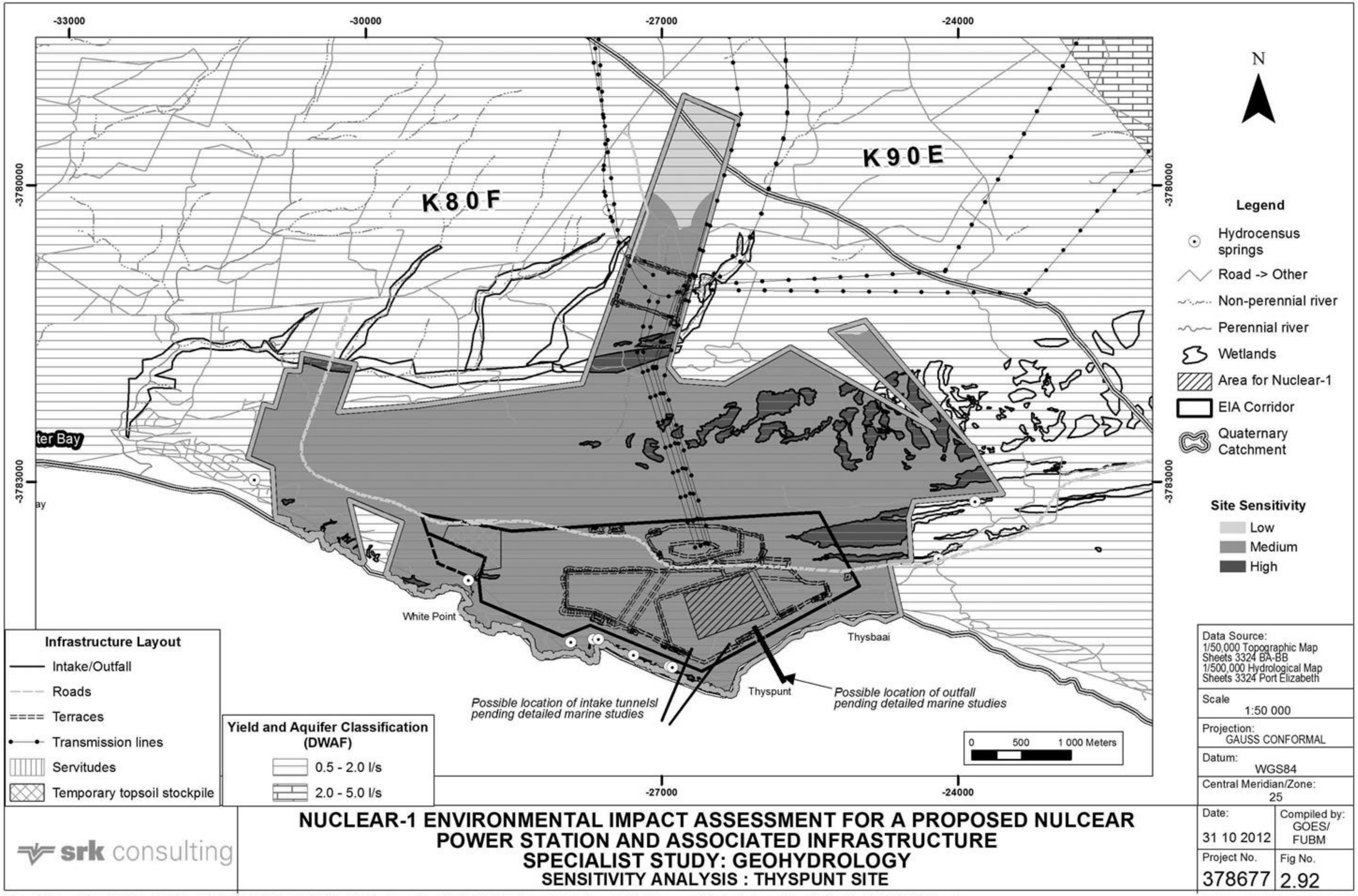
Revision: C Date: 11 11 2014



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Revision: C Date: 02 12 2014

3 IMPACT IDENTIFICATION AND ASSESSMENT

Four potential environmental impacts involving groundwater have been identified:

- Depletion of local aquifers;
- Degradation of ecologically sensitive wetlands / phreatophtes/ seeps / springs, by pumping, cut-off structures or disruption of flow paths by foundations;
- Contamination;
- Contamination of the shore zone.

Two potential impacts of groundwater on the proposed power station have been identified:

- Flooding by groundwater;
- Degradation of infrastructure.

These potential impacts (both positive and / or negative) are assessed for each of the two project phases, i.e. construction and operation, in the following sections. Potential direct, indirect and / or cumulative environmental impacts are identified. .

The impacts are discussed in **Section 4**.

The significance of the impacts is assessed both without and with recommended effective mitigation. Where appropriate, essential mitigation measures and optional mitigation measures are given.

A statement of acceptability is given, whereby the impacts are assessed in terms of whether they constitute a fatal flaw from an environmental and / or legal perspective.

An appropriate monitoring and review programme to track the efficiency of the mitigation measures is also recommended. The monitoring and review programmes also stipulate the timeframes for mitigation measures and the frequency for monitoring.

4 ENVIRONMENTAL ASSESSMENT

4.1 Construction Phase

Refer to impact assessment **Table 4.4** and **Table 4.6** for the three sites. The discussion of these potential impacts during the construction phase is common to each of the three sites, since the nature and significance of the impacts are generally the same across all three sites.

4.1.1 Impacts of the proposed development on the environment

Depletion of Local Aquifers

Dewatering the construction areas will result in lowering of the water table, which could deplete the local primary aquifer system. Potential impacts relating to a declining water table include the threat of decreased yields of existing production boreholes / wellpoints, drying up of wetlands, loss of phreatopytes and subsidence, which could have a detrimental impact on land and buildings. Two wellfields, the Witzand and Aquarius wellfields, are located in relatively close proximity to the Duynefontein site (the latter is located on the site). However, the latter is only sparsely used and for a non-essential purpose. These wellfields could be impacted on, with their sustainable exploitability decreasing due to decreasing borehole yields, although numerical modelling has indicated that this is unlikely. Without mitigation the intensity is assessed to be low as the natural processes (i.e. depth to groundwater, sustainable borehole yields, etc.) would be negligibly altered. The duration of this potential impact is assessed to be short-term, as once the excavation works have been completed, the water table will soon attain its pre-construction natural depth below ground level, as seen at the KNPS. Mitigation measures could include managed artificial recharge of the primary aquifer with pumped groundwater near to sensitive features and installing cut-off walls around the dewatered excavation areas. With mitigation, the intensity is assessed to be low.

The extent of the influence of dewatering on groundwater levels was determined by numerical modelling and shown to be of limited extent, especially with the installation of cut-off walls.

At the Bantamsklip and Thyspunt sites, there are no cumulative impacts relating to depletion of the aquifer systems as there are no other significant developments and / or large-scale groundwater abstraction areas within the indicated area of influence of dewatering/ groundwater control.

Groundwater could be used for start-up water supply at the Duynefontein and Thyspunt sites based on aquifer potential.

Degradation of Ecologically Sensitive Wetlands / Phreatophytes / Seeps / Springs

Potential impacts relating to a declining water table may include the drying up/degradation of any coastal springs, seeps, phreatophytes and / or wetlands in close proximity to the sites. These bodies sustain sensitive ecosystems and are mostly fed and sustained by groundwater from the primary aquifers. The survival of such ecosystems may be threatened due to dewatering activities and/or foundations or cut-off walls. The *intensity* is assessed to be *medium*, as the functioning of such coastal springs, seeps and / or wetlands may be temporarily modified. The duration will be *short-term* during construction but could be *long-term* during operation. With mitigation, the *intensity* is assessed to be *low*. The additional wetlands/groundwater monitoring work has also shown that the Langefonteinvlei at Thyspunt is perched above the water table in its southern and western parts.

An assessment of impacts to these surface freshwater ecosystems has been carried out and includes identification and mapping of the wetlands in the vicinity of the sites, classification of the wetlands and an assessment of wetland sensitivity and importance (Day, 2007a and Day, 2007b). Modelling has shown that it will be possible to locate the NPS within the EIA Corridor so that these impacts will be minimal to absent. This is dealt with in detail in the wetlands report.

Groundwater Contamination

The groundwater resources underlying the sites may potentially be impacted by the following:

1. Saline intrusion: This will have to be considered during the design of a dewatering scheme at any of the sites;
2. Hydrocarbon contamination: Downward migration of leaked and / or spilled fuel, oil and grease into the underlying aquifer system;
3. Hazardous waste contamination: Downward migration of contaminants from on-site waste storage areas;
4. Organic and bacterial (microbiological) contamination: Downward migration of contaminants from leaking and / or spilling on-site sewage facilities.

The *intensity* of saline intrusion is assessed to be *medium* as the natural quality of the groundwater, especially in the primary aquifers, may temporarily deteriorate as seawater (which has a significantly greater concentration of salts compared to the groundwater) migrates against the natural hydraulic gradient towards the site. The reversal of the hydraulic gradient from coast to land would be a direct result of the dewatering activities. It is expected that the time frame for which this impact will be experienced is *medium-term*, as the environment will gradually re-establish equilibrium.

In terms of hydrocarbon, hazardous waste, and organic and bacterial (microbiological) contamination, the *intensity* is assessed to be *low*, as the natural quality of groundwater at the sites should not be notably degraded. It is presently not known what types of hazardous wastes may be treated, stored, transported or disposed of, or otherwise managed, at the sites. However, examples are paints and solvents, vehicle wastes (e.g. used motor oil, etc.), mercury-containing wastes (e.g. thermometers, switches, fluorescent lighting, etc.), caustics and cleaning agents and batteries.

It is expected that without mitigation, the quantity of potential non-radioactive contaminants used and / or stored, and spilled and / or leaked at the sites, will be insufficient to extensively contaminate the primary aquifers. With mitigation, the *intensity* remains *low*. The impact will be of a *short-term* nature. For example, the water quality analyses from boreholes drilled at the Duynefontein site show no indications of degradation of quality due to construction of the KNPS.

4.1.2 Impact of the environment on the proposed power station

Flooding by Groundwater

As the natural groundwater levels at the sites are shallow, flooding will occur immediately when excavations extend below the water table. This potential impact refers to the natural effect of the environment on the construction works, whereby groundwater inflow into excavations will hinder and be a danger to construction activities. Without mitigation the *intensity* (i.e. the management of the impact in relation to the sensitivity of the receiving environment) is assessed to be *medium* because the natural geohydrological processes (i.e. movement of groundwater) will continue, albeit in a modified way. Localised flow directions may be altered as a result of the change in hydraulic gradient. However, the *duration* of this potential impact is assessed to be *short-term*, as once the excavation works have been completed, the environment will mostly recover to equilibrium with groundwater levels and flow directions achieving pre-construction conditions, as happened at the KNPS. With mitigation, the *intensity* is assessed to be *low*.

Degradation of Infrastructure

Corrosive / aggressive groundwater may impact on foundations and buried services. Corrosion is a complex series of reactions between the water and metal surfaces, the building structure of concrete and cement and materials in which the water is stored or transported. With respect to the corrosion potential of groundwater, the primary concerns include the potential presence of toxic metals, such as lead and copper; deterioration and damage to infrastructure.

In scale-forming water, a precipitate or coating of calcium or magnesium carbonate can form on the inside of the piping. This coating can inhibit the corrosion of the pipe, because it acts as a barrier, but it can also cause the pipe to clog. Water with high levels of Na, Cl, or other ions will increase the conductivity of the water and promote corrosion. Corrosion can also be accelerated by:

- low pH (acidic water) and high pH (alkaline water);
- high flow rate within the piping;
- high water temperature;
- oxygen and dissolved $CO_{2;}$
- high dissolved solids, such as: salts, sulfates;
- corrosion related bacteria and electrochemical corrosion;
- presence of suspended solids, such as sand, sediment, corrosion by-products, and rust.

The Langelier index indicates the corrosivity of water (Langelier Saturation index). If its value is lower than - 0.5, then water is corrosive, if it is higher than 0.5 then the water has a high scaling potential, and it can form deposits in piping. The Langelier Index is calculated using the following variables:

- TDS = Total dissolved solids (mg/L);
- T = Temperature in ºC;
- C = Calcium hardness (concentration of $CaCO_3$ mg/L);
- A = Alkalinity (concentration of $CaCO_3$ mg/L);
- pH = pH of the water.

The Langelier index has been calculated for groundwater in the monitored boreholes at the three sites and are listed in **Table 4.1**, **Table 4.2** and **Table 4.3** and give an indication of the degradation capacity of the groundwater with respect to corrosivity and scaling capacity.

Table 4.1: Langelier Indices for the Duynefontein Site with Degradation Indication (corrosion or scaling)

Site	Borehole ID	LSI	LSI (1936)		LSI (Carrier, 1965)	
			LSI Range	Indication	LSI Range	Indication
Duynefontein	SRK-KG1	-1.63	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-2 < LSI < -0.5	Serious corrosion
	SRK-KG2	0.41	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0 < LSI < 0.5	Slightly scale forming and corrosive
	SRK-KG4	0.68	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0.5 < LSI < 2	Scale forming and non corrosive
	SRK-KG6	0.36	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0 < LSI < 0.5	Slightly scale forming and corrosive
	SRK-KG8	-0.46	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-0.5 < LSI < 0	Slightly corrosive but non scale forming
	SRK-KG9	-0.60	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-2 < LSI < -0.5	Serious corrosion

Results indicate that corrosion of subsurface installations could occur at this site and so corrosion-resistant materials should be used for such applications.

Table 4.2: Langelier Indices for the Bantamsklip Site with Degradation Indication (corrosion or scaling)

Site	Borehole ID	LSI	LSI (1936)		LSI (Carrier, 1965)	
			LSI Range	Indication	LSI Range	Indication
Bantamsklip	BP2	0.37	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	0 < LSI < 0.5	Slightly scale forming and corrosive
	BP3	-0.50	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-0.5 < LSI < 0	Slightly corrosive but non scale forming
	BP7	0.28	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0 < LSI < 0.5	Slightly scale forming and corrosive
	BP15	0.16	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0 < LSI < 0.5	Slightly scale forming and corrosive
	BP21	-1.68	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-2 < LSI < -0.5	Serious corrosion
	BP26	-2.65	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-2 < LSI < -0.5	Serious corrosion
	BP27a	-0.24	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-0.5 < LSI < 0	Slightly corrosive but non scale forming

Results indicate that corrosion of subsurface installations could be a problem at this site and so corrosion-resistant materials should be used for such applications.

Table 4.3: Langelier Indices for the Thyspunt Site with Degradation Indication (corrosion or scaling)

Site	Borehole ID	LSI	LSI (1936)		LSI (Carrier, 1965)	
			LSI Range	Indication	LSI Range	Indication
Thyspunt	SP7	1.30	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0.5 < LSI < 2	Scale forming and non corrosive
	RP7	-0.50	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-0.5 < LSI < 0	Slightly corrosive but non scale forming
	RP8	0.90	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0.5 < LSI < 2	Scale forming and non corrosive
	RP10	1.25	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0.5 < LSI < 2	Scale forming and non corrosive
	RP12	-0.45	< 0	Water is undersaturated with respect to calcium carbonate. Undersaturated water has a tendency to remove existing calcium carbonate protective coatings in pipelines and equipment.	-0.5 < LSI < 0	Slightly corrosive but non scale forming
	RP13	0.08	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0 < LSI < 0.5	Slightly scale forming and corrosive
	RP14	0.67	> 0	Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur.	0.5 < LSI < 2	Scale forming and non corrosive

Results indicate that corrosion of subsurface installations is unlikely to be a problem at this site if no mitigation is applied. However, formation of scale could be a problem and will need to be taken into account for design and maintenance purposes as appropriate.

Contamination of the Shore Zone

It has been shown that groundwater naturally flows towards the ocean. For this reason, any contaminated groundwater will discharge to the sea and could potentially be toxic to marine life. Although any contaminants may be concentrated in a small area, flow will be limited to a small area as well and non-radioactive contaminants will readily dissipate.

There is only one potential impact of groundwater on the shore zone during construction of an NPS, namely the disruption of habitat.

Impacts during operation include:

- Mortality of organisms;
- Changes in species composition;
- Accumulation of radioactivity in marine organisms.

The above may in turn pose risks to the NPS which would include blockage of water intakes and fouling of the cooling systems by marine organisms.

Table 4.4: Impact Assessment for the Duynefontein Site During the Construction Phase

Impact	Nature	Intensity	Extent	Duration	Impact on Irreplaceable Resources	Consequence	Probability	SIGNIFICANCE
Impact 1: Flooding of the excavated areas by groundwater	Negative	Medium	Low	Low	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 2: Decreased yields of existing production boreholes	Negative	Medium	Low	Low	Low	Medium	Low	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 3: Intrusion of saline water	Negative	Medium	Low	Medium	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 4: Contamination of groundwater	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low

Table 4.5: Impact Assessment for the Bantamsklip Site During the Construction Phase

Impact	Nature	Intensity	Extent	Duration	Impact on Irreplaceable Resources	Consequence	Probability	SIGNIFICANCE
Impact 1: Flooding of the excavated areas by groundwater	Negative	Medium	Low	Low	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 2: Decreased yields of existing production boreholes	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 3: Intrusion of saline water	Negative	Medium	Low	Medium	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 4: Contamination of groundwater	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low

Table 4.6: Impact Assessment for the Thyspunt Site During the Construction Phase

Impact	Nature	Intensity	Extent	Duration	Impact on Irreplaceable Resources	Consequence	Probability	SIGNIFICANCE
Impact 1: Flooding of the excavated areas by groundwater	Negative	Medium	Low	Low	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 2: Decreased yields of existing production boreholes	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 3: Intrusion of saline water	Negative	Medium	Low	Medium	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 4: Contamination of groundwater	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low

4.2 Operational Phase

Refer to impact assessment, **Table 4.7**, **Table 4.8** and **Table 4.9**. The KNPS has been in operation for 27 years and yet the results of site groundwater monitoring do not indicate any significant observable impacts on the site or surrounding groundwater regime. This has been taken into consideration in the impact assessment.

Flooding by Groundwater – Direct Impact

As the natural groundwater levels at the sites are shallow, flooding will occur immediately when excavations extend below the water table. This potential impact refers to the natural effect of the environment on the construction works, whereby groundwater inflow into excavations will hinder and be a danger to construction activities. Without mitigation the *intensity* (i.e. the management of the impact in relation to the sensitivity of the receiving environment) is assessed to be *medium* because the natural geohydrological processes (i.e. movement of groundwater) will continue, albeit in a modified way. Localised flow directions may be altered as a result of the change in hydraulic gradient. However, the *duration* of this potential impact is assessed to be *short-term*, as once the excavation works have been completed, the environment will mostly recover to equilibrium with groundwater levels and flow directions achieving pre-construction conditions. With mitigation, the *intensity* is assessed to be *low*.

The effects of global warming in terms of sea level rise may have an impact on the local groundwater base levels. Indications from the numerical modelling are that a groundwater level rise of <1 m can be expected over the sites. However, this is not considered to be significant from a flooding perpsective. The freshwater / saline water interface will shift inland under this scenario.

Contamination – Direct Impact

The potential impacts during the operational phase remain the same as those during the construction phase (other than saline intrusion, which will not be a potential impact). However, three additional potential impact scenarios relating to contaminating the groundwater resources exist during the operational phase, namely:

1. Operation under normal conditions,
2. Non-nuclear accidents;
3. Nuclear accidents.

Operation under normal conditions is the only scenario covered in this report, in line with an international example of a NPS EIA (US Nuclear Regulatory Commission, 2006). Release of gaseous and liquid emissions at the sites could give rise to *long-term* impacts of *Low* intensity and of *local* extent. Air emissions of radioactivity could impact on areas well beyond the site boundaries, as has been indicated by the numerical modelling for ^{3}H. However, under normal design operational conditions such releases will be minimal and within accepted dose levels as set by the National Nuclear Regulator (NNR). This has been demonstrated by the operation of the KNPS over the past 30 years. The results of the 2010 environmental surveillance programme at this site do not indicate any significant adverse effect on the environment. They also do not show any significant increase in the levels of radioactivity in environmental samples over pre-operational levels, with the exception of marine and sewage sludge samples (Eskom, 2011). The reactors will also be designed to contain accidents in the core area to within the reactor shields. Impacts of such an accident scenario are therefore not considered here.

Leaks of any radioactivity into the subsurface and ultimately into the underlying aquifers (both the primary and secondary aquifers) are highly unlikely but will not directly affect existing groundwater users (but will affect the receiving environment). Assuming that an impermeable cut-off wall is installed around the reactor area (as is the standard practice in nuclear power station design), this will contain any liquid contaminants emanating from this source. In the highly unlikely event of such contamination, it will be detected by the monitoring system and remediated

Degradation of Infrastructure

This impact will be of greater significance during the operational phase than during the construction phase, as the foundations and buried services will be established. Indications are that the groundwater at the Duynefontein and Bantamsklip sites could be corrosive. Use of corrosion-resistant materials must be considered for infrastructure likely to come into contact with groundwater.

Table 4.7: Impact Assessment for the Duynefontein Site During the Operational Phase

Impact	Nature	Intensity	Extent	Duration	Impact on Irreplaceable Resources	Consequence	Probability	SIGNIFICANCE
Impact 1: Radioactive and toxic contamination of groundwater	Negative	Low	Low	High	Low	Medium	Low	Low - Medium
With mitigation	Negative	Low	Low	High	Low	Low	Low	Low
Impact 2: Hydrocarbon contamination of groundwater	Negative	Low	Low	Low	Low	Low	High	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 3: Organic and bacteriological contamination of groundwater	Negative	Low	Low	Low	Low	Low	High	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 4: Decreased yields of exisitng production boreholes	Negative	Low	Low	High	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 7: Intrusion of saline water	Negative	Medium	Low	Medium	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low

Table 4.8: Impact Assessment for the Bantamsklip Site During the Operational Phase

Impact	Nature	Intensity	Extent	Duration	Impact on Irreplaceable Resources	Consequence	Probability	SIGNIFICANCE
Impact 1: Radioactive and toxic contamination of groundwater	Negative	Low	Low	High	Low	Medium	Low	Low - Medium
With mitigation	Negative	Low	Low	High	Low	Low	Low	Low
Impact 2: Hydrocarbon contamination of groundwater	Negative	Low	Low	Low	Low	Low	High	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 3: Organic and bacteriological contamination of groundwater	Negative	Low	Low	Low	Low	Low	High	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 4: Decreased yields of existing production boreholes	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 7: Intrusion of saline water	Negative	Low	Low	Low	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low

Table 4.9: Impact Assessment for the Thyspunt Site During the Operational Phase

Impact	Nature	Intensity	Extent	Duration	Impact on Irreplaceable Resources	Consequence	Probability	SIGNIFICANCE
Impact 1: Radioactive and toxic contamination of groundwater	Negative	Low	Low	High	Low	Medium	Low	Low - Medium
With mitigation	Negative	Low	Low	High	Low	Low	Low	Low
Impact 2: Hydrocarbon contamination of groundwater	Negative	Low	Low	Low	Low	Low	High	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 3: Organic and bacteriological contamination of groundwater	Negative	Low	Low	Low	Low	Low	High	Low - Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 4: Decreased yields of exisitng production boreholes	Negative	Low	Low	High	Low	Low	Low	Low
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low
Impact 7: Intrusion of saline water	Negative	Medium	Low	Medium	Low	Medium	High	Medium
With mitigation	Negative	Low	Low	Low	Low	Low	Low	Low

4.3 Fatal Flaws (Statement of Acceptability)

The geohydrological specialist study indicates that there are no fatal flaws in respect of groundwater dynamics, conditions and / or use with respect to establishing a NPS at any of the three sites. This assumes normal operation of the NPS.

4.4 No Go Option

In the event that the sites are not developed for NPSs, Eskom will sell the Bantamsklip and Thyspunt properties and non-essential parts of Duynefontein could also be sold. In this scenario the impact is seen to be of *low* intensity, *neutral* consequence and *low* significance for the Bantamsklip site but of *medium* intensity, *negative* consequence and *high* significance for the Thyspunt and Duynefontein sites as it is unlikely that a similar level of site control and preservation of aquifers and ecological features could be enforced or afforded by private land owners/developers as would have been the case with a nuclear site. The main mitigation measure for this scenario would be strict enforcement of conditions applicable to any approved future development of the sites, which would presumably cover preservation of these features.

5 MITIGATION MEASURES

5.1 Mitigation Objectives

Mitigation measures / management actions are recommended in order to aid with the following:

- Minimising or eliminating negative impacts;
- Enhancing beneficial impacts;
- For assistance with the project design to prevent or minimise negative impacts.

5.2 Recommended Mitigation Measures

Dewatering to prevent: Flooding by Groundwater

To mitigate this, the construction area and subsequent excavated areas must be dewatered most likely by constructing a cut-off / diaphragm wall and installing a series of wellpoints, boreholes and sumps. The design of a dewatering scheme is beyond the scope of this specialist study, but the dewatering activity and associated groundwater monitoring programme are considered essential mitigation measures. A form of cut-off wall is considered to be the most suitable and reliable design to minimise the extent of drawdown. The siting of the NPS within the EIA Corridor should take this aspect/impact into account.

A system of cut-off walls, boreholes and wellpoints was successfully used for dewatering/groundwater control for the excavation for the KNPS. 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 thickness of saturated sands at this site was about 14 m and the base of the excavation was at an average of 10 m below sea level. The dewatering design is shown in **Figure 5.1** while **Figure 5.2** is an aerial photograph of the excavation, showing the stable side walls and dry floor. Trucks can be seen on side ramps into the excavation. The time taken for full excavation of the KNPS site was 5.5 months.

A similar system was successfully used for dewatering/groundwater control for excavations for Coega Harbour north of Port Elizabeth. This site was particularly demanding from a safety/design point of view as excavations took place in the tidal zone and below sea level. Men and machinery were working many metres below sea level with only a cut-off wall and some boreholes/wellpoints stopping the excavation from collapsing, which would have had disastrous consequences. Some photographs from the site excavation stage are shown in **Figure 5.3**. The height of the cut-off wall exposed in the first photograph is approximately 10 m. SRK acted as review consultants on this project for the National Ports Authority and can vouch for the effectiveness of this type of integrated groundwater control design.

Figure 5.1: Dewatering Design for the KNPS Excavation (Eskom 2006a)

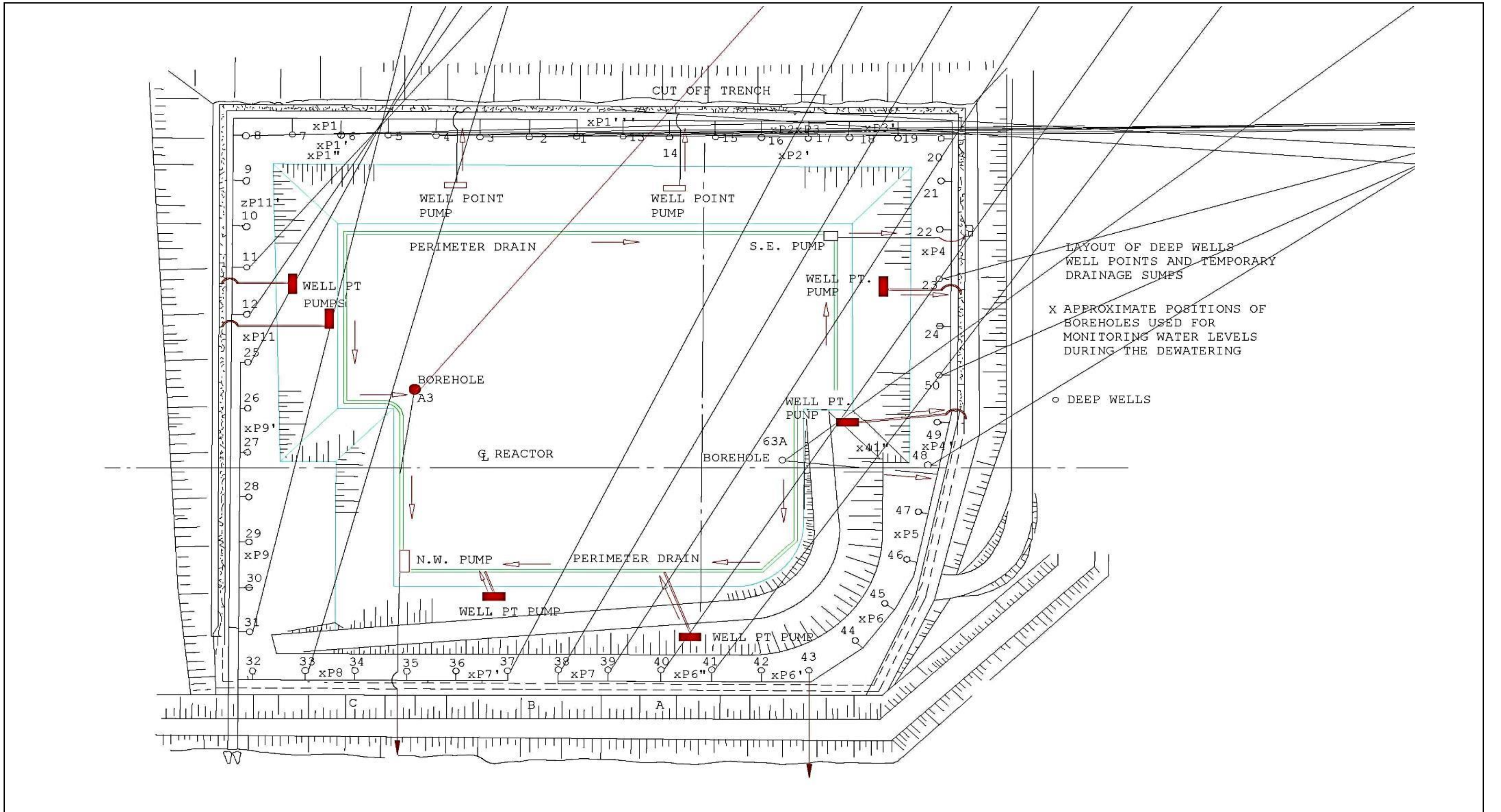

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Figure 5.2: Aerial Photograph of the Excavation for KNPS (after Barker, 1987)

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Figure 5.3: Photographs from the Coega Harbour Excavation Dewatering

Section of the Slurry Cut-Off Wall Exposed in the Excavation

View of the Main Harbour Excavation Showing Central Foundations and Stepped Benches

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In the light of the above examples (and many more world-wide), SRK has full confidence in a) the feasibility of such a design and b) the effectiveness in practice of such a design.

Mitigation Hierarchy: Avoidance

Cut-off Barrier and Monitoring to prevent the Depletion of Local Aquifers

This impact can be mitigated by constructing a cut-off or diaphragm wall, and by carrying out groundwater level monitoring to assess the efficiency of such a design. Monitoring is considered an essential measure so that remedial actions can be carried out timeously, if required. The final design of dewatering schemes has not been established. However, based on results from this study, the construction of such a barrier is considered to be an essential mitigation measure at the Duynefontein and Thyspunt sites. The siting of the NPS within the EIA Corridor should take this aspect/impact into account.

Mitigation Hierarchy: Avoidance

Cut off wall and Monitoring to prevent the Degradation of Ecologically Sensitive Wetlands / Seeps / Springs

This impact can be mitigated by constructing a cut-off wall and by carrying out groundwater level monitoring. Groundwater monitoring is considered an essential measure so that timeous remediation measures can be taken, if required. The final design of dewatering schemes has not been established. However, based on results from this study, the construction of such a barrier is considered to be an essential mitigation measure at the Duynefontein and Thyspunt sites. The siting of the NPS within the EIA Corridor should also take into account the optimal position from this point of view.

Actual measurements of the water table at the KNPS immediately surrounding the foundation cut-off wall during and after the 12-month dewatering period are instructive (Eskom 2006a, Chapter 9). This showed that the water table dropped by approximately 2 m and then returned to an equilibrium state as the foundation area was backfilled but with a *higher* inland water level than for the natural state. The water table on the seaward side of the foundation area was lowered but did not drop below sea level.

Abstraction of groundwater for site start-up supply from aquifers with direct links to freshwater ecosystems should take place >500 m from the nearest boundary of such systems.

Mitigation Hierarchy: Avoidance

Prevention of Contamination

Saline intrusion will have to be considered during the design of a dewatering scheme at the sites. To ensure that groundwater is not contaminated due to seawater ingress during dewatering, groundwater levels between the excavation and the coastline will have to be maintained above sea level by injecting the water abstracted from the dewatering holes into holes drilled near the coastline. This will be accompanied by routine monitoring, which is an essential mitigation measure.

Contamination of the soil and groundwater by accidental spills of fuel, oil and / or grease must be kept to a minimum by applying a good 'housekeeping' approach (essential mitigation measure). Procedures/protocols must be in place to quickly and effectively repair any leakages and remove the contaminated soil. This soil must be collected and disposed of at a suitably licensed waste disposal facility (essential mitigation measure).

Fuel, oil and / or grease should be stored on paved areas surrounded by oil catches, i.e. a sump surrounding the storage area to 'catch' all spilled fuel, oil and / or grease (essential mitigation measure). This should be cleaned / removed regularly and disposed of at a suitably licensed waste disposal facility (essential mitigation measure).

All industrial wastewater that will be generated at the sites from various operations must be safely and effectively processed and disposed of (essential mitigation measure).

Contamination of the soil and groundwater by leaks and spillages from on-site sanitation facilities must be kept to a minimum by conducting regular checks and repairs of any such leaks and spillages (essential mitigation measure). All ablution facilities and the discharge process of raw sewage must be designed to prevent potential contamination (essential mitigation measure).

Should the results of groundwater monitoring indicate that contamination has occurred, remedial procedures (which must be formulated prior to the start of construction activities) must be put in place with immediate effect.

A standard mitigation protocol cannot be currently presented, as the nature and extent of contamination would have to be firstly understood and addressed. Once contamination has been detected (predominantly based on a deterioration of groundwater quality), a site assessment must be undertaken.

This assessment must include identifying the source of contamination and the scale of the problem. The extent of contamination must be investigated by augering a series of shallow, temporary exploration holes and collecting samples for analysis.

Once these tasks have been undertaken, the problem must be dealt with accordingly. Minor, insignificant levels of contamination can be mitigated with natural attenuation. Should the extent of contamination prove significant, the source of contamination must be removed and / or repaired, thereby preventing further contamination. All contaminated soil and groundwater must be disposed of according to environmentally acceptable procedures, with full cooperation from the relevant authorities and full documentation on the quantities and methods of disposal.

Based on the existing KNPS construction, the risk of radioactive contamination of groundwater from the existing nuclear islands is unlikely as the inherent design and safety features mitigates this. In the improbable event of a radioactive leakage from the existing nuclear island, the aseismic vault (i.e. built to withstand earthquakes) would prevent any contamination. Regular inspection of the aseismic vault is conducted to ensure that groundwater does not permeate through the retaining wall of the aseismic vault (Eskom, 2006a) at KNPS and this must also apply to the proposed NPSs. Assuming that an impermeable cut-off wall is installed around the reactors, as is standard practice in the design and construction of nuclear power stations, this will assist in containing any liquid contaminants emanating from this source.

The NPS must be sited optimally based on, *inter alia*, further detailed geological, geotechnical and geohydrological investigations. Faults and fracture zones should be avoided as far as practically possible, thus minimising the risk of these features becoming pathways for migration of contamination.

Similarly, the waterproofing system applied to external walls below ground level is designed to prevent the ingress of groundwater into the buildings, as well as the egress of radioactive substances out of the buildings (Eskom, 2006a). This must also apply to the proposed NPSs.

It is optional to establish a 'lessons learned' task team to address inadvertent, unmonitored liquid releases of radioactivity from existing commercial nuclear power stations, including the KNPS. This task team should review previous incidents, identify lessons learned from these events, and determine what, if any, changes are needed in the safe operation of the proposed NPSs.

Mitigation Hierarchy: Reduction

5.3 Recommended Monitoring and Evaluation Programme

5.3.1 Purpose of Monitoring

The investigation of the three sites and the understanding gained of their hydrogeological characteristics indicate that continuation of the groundwater monitoring programme initiated in 2008 is essential, namely:

- Prior to and during construction;
- During operation.

Pre-construction monitoring must focus on the following:

- **Groundwater levels.** This will provide valuable information on seasonal trends and response to extreme weather conditions, i.e. high rainfall events and droughts.
- **Wetlands/seeps**. These must be monitored to determine interaction with groundwater and the possible long-term effect (quality, water level/flow rate, as applicable) of groundwater control measures.
- **Groundwater quality**. This must include monitoring of selected radionuclides, macro-groundwater quality and trace elements, as described in more detail below.

A groundwater monitoring programme is essential, as it will provide:

- Baseline information on aquifer behaviour for a sufficient period (four and a half years so far) before construction commences;
- Information on groundwater quality at the sites in order to obtain time series groundwater quality data of the selected constituents, to verify selection of management actions and to determine the effectiveness of those actions;
- A reference database from which remediation programmes can be developed, if required;
- An opportunity to update assumptions, models and conclusions, although it considered to be highly unlikely that information will come to light to require such updates;
- A legally defensible database against which any possible future claims against Eskom regarding environmental contamination or human health risk can be measured.

5.3.2 Monitoring Network Design

The following groundwater monitoring programme was operational since about mid-2008 (start date varies from site to site) to September 2013:

- Both shallow (primary aquifer) and deeper (secondary aquifer) monitoring boreholes at the sites are equipped with automatic groundwater level / temperature recorders. A barometric logger has been installed to record the barometric pressure variation in order to correct the groundwater level data for barometric variation. Data were downloaded on a quarterly basis. Since September 2013, these loggers have still been operational but the data has not been downloaded;
- Wetlands were monitored by means of piezometers (water levels and quality);
- Field measurements were carried out monthly for groundwater levels, pH, redox and EC;
- Groundwater samples were taken for macro- and micro-chemical, stable isotope and selected radionuclide analyses in May and November.

5.3.3 Analysis of Groundwater Quality

Laboratory analyses include a full suite of cations (Na, K, Ca, Mg, NH_4), anions (Cl, SO_4, NO_3, NH_3, PO_4, HCO_3), heavy metals (Fe, Mn, Cr, Zn, Co, Pb, Cu, Cd), trace elements (F), gross beta and alpha activity and selected radionuclides of e.g. U, Th, Cs, Sr and Ra, plus ^{3}H and ^{14}C and any additional determinands required for assessment of aggressiveness of the water.

5.3.4 Updating of Numerical Models

The numerical model should be used on a regular basis, for running all potential predictive scenarios under consideration, so as to inform management planning decisions. It is recommended that the numerical model be regularly verified and updated using the most recent monitoring data, at a minimum interval of two years. The current models require re-calibration with the latest monitoring and climatic data, as well as transient calibration (with pumping test data).

6 CONCLUSIONS AND RECOMMENDATIONS

Four potential environmental impacts involving groundwater have been identified:

- Flooding by groundwater;
- Degradation of infrastructure
- Depletion of local aquifers;
- Contamination.

The impact rating of the potential environmental impacts is summarised as follows for the construction and operational phases:

Table 6.1: Impact Significance Summary Rating

Impact	Significance Rating	
	Without Mitigation	With Mitigation
Impacts of the environment on the NPS		
Flooding by groundwater	*Medium* at all three sites	*Low* at all three sites
Degradation of infrastructure	*Medium* at Duynefontein and Bantamsklip sites	*Low* at all three sites
Impacts of the NPS on the environment		
Depletion of local aquifers	*Medium* at Thyspunt and Duynefontein *Low-Medium* at Bantamsklip	*Low* at all three sites
Non-radioactive contamination of groundwater	*Medium* at all three sites	*Low* at all three sites
Gaseous and liquid radioactive emissions of groundwater (under normal operational conditions)	*Low-Medium* at all three sites	*Low* at all three sites
Contamination by seawater intrusion	*Low* at all three sites	*Low* at all three sites

The mainly low ratings are largely a function of the sites being situated in coastal zones with groundwater being at/near the end of its flow path and minimal downstream receptors.

Groundwater could be developed for use in start-up site operations at the Duynefontein and Thyspunt sites.

Essential mitigation measures include the following:

- Use of cut-off walls around excavations to help limit the spread of drawdown during construction and contamination during operation;
- Use of managed artificial recharge of groundwater pumped from excavations during dewatering to maintain wetlands/springs/seeps and phreatophytes;
- Siting of the NPS foundation excavation within the EIA Corridor such that the impacts identified can be reduced in significance, e.g. avoiding major, seismically capable faults, fracture zones, sensitive wetlands, coastal seeps/wetlands (assumes groundwater control mitigation measures are in

place). Setting the footprint back from the coast is in any case favoured by Eskom to reduce plant corrosion;

- Use of corrosion-resistant foundations, pipes and fittings where infrastructure will be located below the water table;
- The potential for scale formation must be taken into consideration in design and maintenance at the Thyspunt site;
- Use of nuclear reactor design meeting the NNR's requirements for normal operational dose emissions and containment of accident emissions;
- Development of a remediation/mitigation protocol prior to construction so that measures are documented and in place to deal rapidly with any on-site contamination incidents or spread of drawdown beyond expected limits.

Based on the geohydrological assessment presented in this specialist report, all three sites are environmentally acceptable, in terms of groundwater, for the development of a NPS.

The confidence level in the conclusions reached in this specialist report is high. However, as noted earlier, it is not possible to obtain absolute values for many geohydrological parameters and there will always be some uncertainties in this regard.

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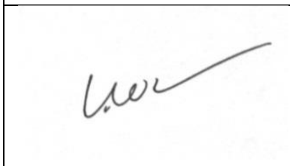
Specialist signature	 ....P Rosewarne Pr Sci Nat
Date	18 September 2015