Preliminary Assessment of supplying ESKOM's Ankerlig Power Station with water from local groundwater resources

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Savannah Environmental (Pty) Ltd

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SRK Consulting
Engineers and Scientists

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Abstract

In order to supplement the need for new peaking electricity generation capacity, Eskom Holdings Limited (ESKOM) proposes to expand their Ankerlig Open Cycle Gas Turbine (OCGT) power generation facility at Atlantis. The water requirement of the upgraded power station will vary between 500 and 5,000 m^3/day depending upon the type of cooling-system adopted. Savannah Environmental (Pty) appointed SRK Consulting to carry out a preliminary study to assess the viability of meeting these water requirements from groundwater resources with a 15km radius of the power station.

The study area was subdivided into eight Groundwater Resource Units (GRU's) in which the aquifer types, groundwater quality, borehole and aquifer yield potential are assessed. The long-term sustainable yield of all the aquifer systems in the study area is conservatively estimated at 6.7 Mm^3/a during periods of normal rainfall. The so-called Atlantis Primary Aquifer System is the only major groundwater resource in the study area and it extends across five of the identified GRU's. Unfortunately, this aquifer has, to a large extent, been fully developed. However, a number of potential groundwater development options are recommended for further investigation. Depending upon the water requirements of the Ankerlig Power Station, these are:

- If ESKOM adopts a zero-discharge system and its water requirements are ~500 m^3/day it is recommended that the following options should be investigated:
  - The feasibility of developing a wellfield in the APAS (Witzand GRU) about 1 to 2 km due west and/or south-west of the power station; or
  - Developing a wellfield in the APAS (Brakkefontein GRU), some 3.5km southeast of the power station.
  - Purchasing treated waste-water from the sewage treatments works.
- If ESKOM does not adopt a zero-discharge system and their water requirements are in the order of 5,000 m^3/day, the following options should be further investigated in the following order of priority:
  - Negotiating with the CCT to purchase groundwater from their Witzand and/or Silverstroom Wellfields.
  - The feasibility of utilising ESKOM's existing relatively high-yielding boreholes in the Aquarius Wellfield. The sustainable yield of this wellfield is ~48,000 m^3/a.
  - The groundwater yielding potential of NW-trending lineament (fault) passing through the centre of the Wesfleur GRU should be investigated, especially along its extension beneath the APAS just to the north of Atlantis. The north-westerly extension of this lineament into the Mamre Unit should also be investigated, especially along the Modder River.

  It is however unlikely that the power stations water requirements of 1.825 Mm^3/a can be meet from any one the above groundwater development options.

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Glossary of Terms

Aquifer: A geological formation capable of supplying economic volumes of groundwater.

Aquitard: A saturated geological unit with a relatively low permeability that retards and, but does not prevent the movement of water; while it may not readily yield water to boreholes and springs, it may act as a storage unit.

Andesite: Grey, fine-grained volcanic igneous characterised by the presence of sodium-rich plagioclase and one or more mafic minerals such as biotite, hornblende, or pyroxene. It often contains small, visible crystals (phenocrysts) of plagioclase.

Cenozoic: The most recent era of geologic time, from about 65 million years ago to the present. The Cenozoic Era is characterized by the formation of modern continents and the diversification of mammals and plants. Humans first appeared near the end of this era

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

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

Facies: A body of sedimentary rock distinguished from others by its lithology, geometry, sedimentary structures, proximity to other types of sedimentary rock, and fossil content, and recognized as characteristic of a particular depositional environment

Fractured-rock Aquifer: Groundwater occurring within fractures and fissures in otherwise impermeable hard-rock formations.

Greywacke: A variety of dark grey, fine- to coarse-grained sandstones that contain abundant feldspar and angular to sub-angular fragments, with a clay-rich matrix. Greywackes are thought to originate in environments where erosion, transportation, and deposition happen so quickly that minerals and rock fragments do not have sufficient time to break down into finer constituents.

Groundwater: Refers to the water filling the pores and voids in geological formations below the water table.

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 Recharge: Refers to the portion of rainfall that actually infiltrates the soil, percolates under gravity through the unsaturated zone (also called the Vadose Zone) down to the saturated zone below the water table (also called the Phreatic Zone).

Groundwater Resource: All groundwater available for beneficial use, including by man, aquatic ecosystems and the greater environment.

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

Major Aquifer System: Highly permeable formations, usually with a known or probable presence of significant fracturing and/or intergranular porosity; 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; aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.

Non-Aquifer: A groundwater body that is essentially impermeable, does not readily transmit water and/or has a water quality that renders it unfit for use.

Non-Aquifer Systems: 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 unusable; groundwater flow through such rocks does take place and needs to be considered when assessing the risk associated with persistent pollutants.

Palaeo-channel: An ancient river channel evident in a geological sequence.

Permeability: The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2{\cdot}d$ or m/d). It is an intrinsic property of the porous medium and is independent of the properties of the saturating fluid; not to be confused with *hydraulic conductivity*, which relates specifically to the movement of water.

Phyllite: A cleaved metamorphic rock, similar to slate but often having a wavy surface and a distinctive luster imparted by the presence of mica

Pollution: The introduction into the environment of any substance by the action of man that is, or results in, significant harmful effects to man or the environment.

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.

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

Small Industrial Users: Means water users who qualify as work creating enterprises that do not use more than twenty cubic metres per day and identified in the Standard Industrial Classification of All Economic Activities (5^{th} edition), published by the Central Statistics Service, 1993, as amended and supplemented, under the following categories:

1: food processing

2: prospecting, mining and quarrying

3: manufacturing

4: construction

Specific Yield: Ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity from that mass.

Tuff: A rock made up of particles of volcanic ash, varying in size from fine sand to coarse gravel

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 *zone of aeration* or *vadose zone*.

Watertable: 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.

List of Abbreviations

APAS	Atlantis Primary Aquifer System
DEADP	Department of Environmental Affairs and Development Planning
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity (Salinity of water)
CMB method	Chloride Mass Balance method
CCT	City of Cape Town
CRD method	Cumulative Rainfall Departure method
EIA	Environmental Impact Assessment
GA	General Authorisation
GEP	Groundwater Exploitation Potential
GRU	Groundwater Resource Unit
GRP	Groundwater Resource Potential
Ma	Million annums
m.amsl	Metres above mean sea level
MAP	Mean Annual Precipitation
m.bgl	Metres below ground level
mS/m	Milli-siemens per metre
m^3/a	Cubic metres per annum
Mm^3/a	Million cubic metres per annum
m^3/m	Cubic metres per month
NGDB	National Groundwater Database
NWA	National Water Act (Act No. 36 of 1998)
OCGT	Open Cycle Gas Turbine
OWB	Overberg Water Board
SAR	South African Railways
SPI	Standard Precipitation Index
SRK	SRK Consulting (SA) PTY LTD

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Assessment of Groundwater as a Water Supply to ESKOM's Ankerlig OCGT Power Station

1 Introduction

In order to supplement the need for new peaking electricity generation capacity, Eskom Holdings Limited (ESKOM) is currently expanding their Ankerlig Open Cycle Gas Turbine (OCGT) power generation facility at Atlantis. The water requirement of the upgraded power station will vary between 500 and 5,000 m^3/day depending upon the type of cooling-system adopted. Savannah Environmental (Pty) appointed SRK Consulting to carry out a preliminary study to assess the viability of meeting these increased water requirements from groundwater resources located within a 15km radius of the power station.

1.1 Nature of the brief

In November 2007, Savannah Environmental (Pty) Ltd appointed SRK Consulting to carry out a preliminary study to assess the feasibility of meeting ESKOM's water requirements at its Ankerlig Power Station from groundwater resources located within 15km of this facility. The specific tasks included:

- Collate, process and evaluate all existing groundwater information (reports, maps and borehole information archived in the DWAF's National Groundwater Database or NGDB).
- Conduct a preliminary desktop assessment of the local hydrogeological conditions, recharge and groundwater exploitation potential, borehole yields, groundwater quality and General Authorisation for the area. This will be based on the DWAF's recently completed Groundwater Resource Assessment Phase II national dataset, as well as available consultancy literature and data.
- Highlight the limitations (if any) of abstracting groundwater and issues surrounding it.
- Data analysis and reporting.

Savannah Environmental stipulated that the quality of the groundwater is not of major importance to the assessment, as it would be treated to meet the requirements of the power station.

2 Background and Brief

2.1 Background Information

2.1.1 Location and Physiography of the Study Area

ESKOM's Ankerlig Open Gas Cycle Turbine (OCGT) Power Station is located in the Atlantis Industrial Area some 40km north of Cape Town (**Figure 1**) and lies within the municipal boundaries of the City of Cape Town (CCT). The study area is broadly defined as an area that lies within a 15km radius of the power station.

The study area falls within the Berg River Water Management Area (WMA) and extends over portions of four Quaternary Catchments, namely G10L, G21A, G21B and G21D (**Figure 1**). The central parts of the study area are poorly drained due to the flat-lying nature of the terrain and an extensive cover of unconsolidated Cenozoic sands which absorb most of the rainfall. The easterly- and northerly-flowing Modder and Groën Rivers drain the northern part of the area. The southern boundary of the study area is formed by the Sout River which discharges into the Atlantic Ocean between Riebeeckstrand and Melkbosstrand. The southerly flowing Swart and Diep Rivers occur to the east of the study area.

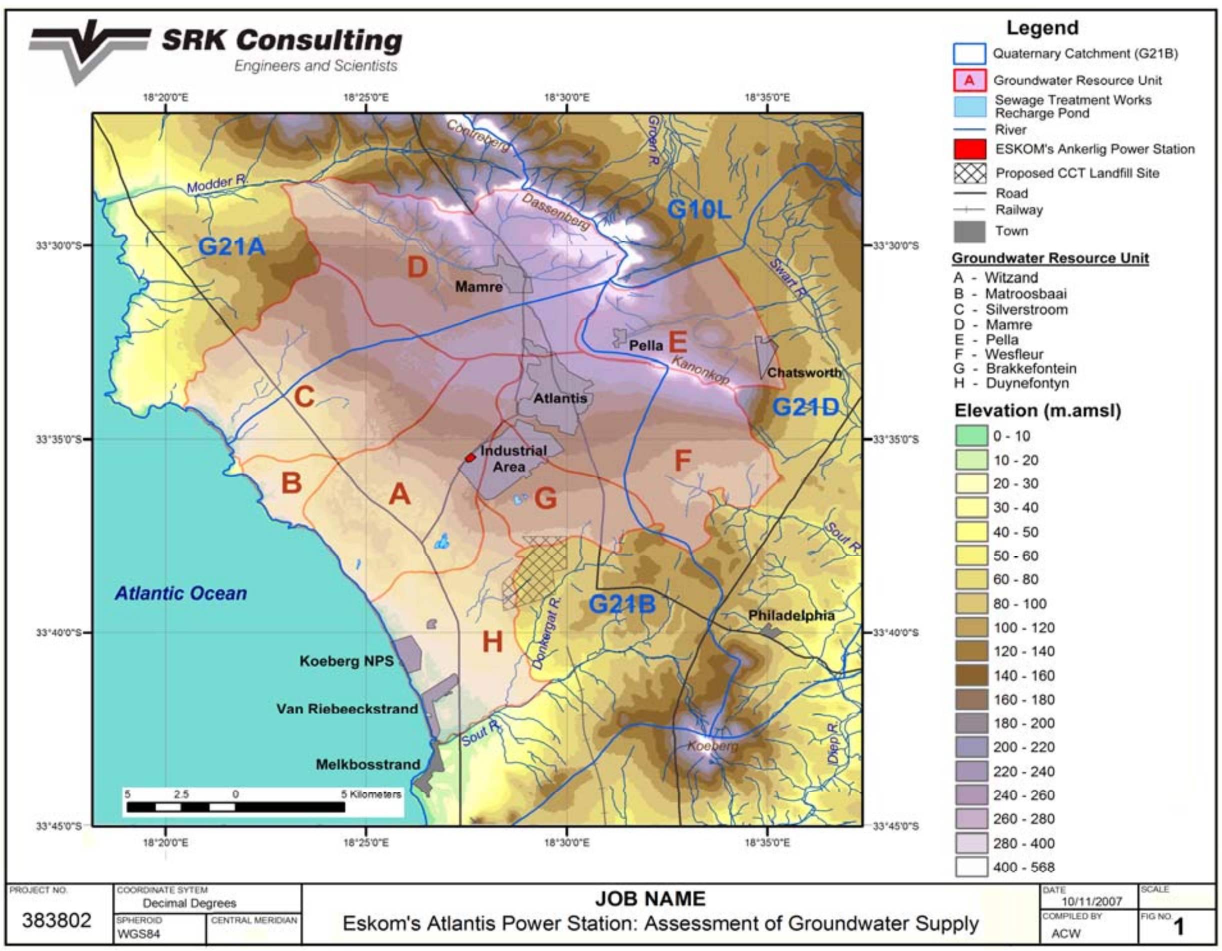

Figure 1: Physiography and Groundwater Resource Units of the Study Area

The coastal plain is 4 to 6km wide and is generally flat and featureless, lying between 10 and 80 metres above mean sea-level (m.amsl). The surface gradient steepens inland towards Atlantis, which lies at ~180 m.amsl. ESKOM's power station is located in the Atlantis industrial area at an elevation of ~130 m.amsl. The Dassenberg Mountain located to the northeast of Mamre forms the highest point (567 m.amsl) in the study area, followed by Kanonkop (418 m.amsl) to the southeast of Pella (**Figure 1**).

2.1.2 Hydrogeology

The geology of the area consists of Cenozoic age aeolian, estuarine and marine sand overlying intensely deformed basement rocks of the Malmesbury Group, which have been intruded by granites of the Darling Pluton (Cape Granit Suite). The Cenozoic sediments are ~25m thick in the vicinity of the Ankerlig Power Station and form part of the so-called 'Atlantis Primary Aquifer System'.

Cenozoic Deposits

Rogers (1980) subdivided the unconsolidated to semi-consolidated Cenozoic deposits of the West Coast Region into a number of stratigraphic units as shown in **Table 1**.

Table 1: Lithostratigraphy of the Cenozoic Sediments

Epoch	Age	Lithostratigraphic Unit		Description	Depositional Environment
		Formation	Member		
Holocene - Pleistocene	1.7	Bredasdorp	Witzand	Calcareous dune sands.	Aeolian
			Langebaan	Calcretized limestone.	Aeolian
			Velddrif	Shelly sand.	Marine
			Springfontyn/Noordhoek	Silica to peaty sand.	Aeolian
Pliocene	5.2	Varswater	CSM	Calcareous sands.	
			PPM (Duynefontein)	Muddy sands with pelletal phosphorite.	Marine
			QSM	Quartzose sand.	Marine
			SGM (Silverstroom)	Shelly gravel.	Marine
Late Miocene	10	'Saldanha'	-	Gravels	Marine
Miocene	22	Elandsfontyn	-	Predominantly coarse sand and gravel, interbedded silty, clayey and peaty layers.	Fluviatile

The following hydrogeological observations have been made in the study area:

- The Silverstroom sediments are all located below sea-level and consist of poorly sorted, angular to semi-angular, greyish brown to dark grey, shell-rich, gravel-bearing clayey sand (Bredenkamp and Vandoolaeghe, 1982).

- The Duynefontyn Member is characterised by moderately sorted, semi-angular to semi-rounded, phosphatic, greyish to greenish white or brownish white, very fine to medium- grained quartzose sand. The sediments are, at places, silty and/or clayey. They only occur sporadically beneath the Springfontyn Member, and are mostly restricted to the aquifer zone below 50m.amsl.

- Sediments of the Springfontyn Member consist mainly of reasonably well sorted, fine- to medium grained, clean, rounded, white to creamy white quartzitic sand, that is locally clayey. This unit is seldom located above an elevation of 50 m.amsl. Coarse-grained sands of this Member form the main transmissive zone of the Atlantis Primary Aquifer System (APAS). In the APAS, this unit attains a maximum thickness of 30m, whilst it is generally located at an elevation of between 10 and 40 m.amsl (Vandoolaeghe, 1983).

- Vandoolaeghe (1983) refers to the 'Mamre Member' which he regarded as the inland equivalent of the Springfontyn Member, with the exception that it has significantly higher silt content. These sediments form the northern limits of the Silverstroom and Witzand Aquifers.

- The Witzand Member consists of semi-consolidated, shell-rich aeolian (dune) sand that is often calcified. In hand specimen these sands appears similar to those of the Springfontyn Member. The Witzand sediments are generally located above the watertable and therefore do not play a significant role in the movement of groundwater in the APAS.

Malmesbury Group

The Tierberg Formation of the Malmesbury Group (830 – 980 Ma) outcrops in the study area (**Figure 2**). This Formation consists mainly of alternating greyish to greenish, medium- to fine-grained greywacke, phyllitic shale, siltstone and immature quartzite (Theron et al, 1992). The sediments are baked to massive bluish-grey hornfels along their contact with the Cape Granite Suite. Altered volcanic rocks of the Blouberg Member outcrop along the coast to the northwest of Bloubergstrand. Here fine red tuff and tuffaceous agglomerate are interbedded with dark red-brown and greenish andesitic lava.

Cape Granite Suite

The Cape granites intruded into the Malmesbury Group between 630 to 530 Ma (Theron et al, 1992). In the study area, the Tierberg Formation is intruded by coarse-grained, porphyritic and biotite-rich granite of the Darling Pluton (**Figure 2**). The biotite granite is considered to be a reaction product of coarse-grained granite and Malmesbury shale. Numerous small dyke-like occurrences of aplogranite are present near Mamre and in the Dassenberg Mountain.

Dolerite Dykes

A number of narrow, north-westerly trending dolerite dykes are known to have intruded into the Malmesbury rocks in the study area.

Atlantis Primary Aquifer System

The ASAP forms part of an almost continuous coastal primary aquifer system that extents from Cape Town in the south to the Olifants River in the north (Bredenkamp and Vandoolaeghe, 1982). The Aquifer System has been subdivided into a number of groundwater units (Vandoolaeghe, 1983), namely:

- Silverstroom;
- Witzand;
- Brakkefontein; and

- Wesfleur (**Figure 2**).

These units were defined according to the groundwater flow regime, as well as palaeo-channels and topographic 'highs' within the Malmesbury bedrock. Therefore groundwater can flow freely between the units in the APAS. Sediments of the Springfontein Member (**Table 1**) form the main transmissive zone of this Aquifer System. The Malmesbury rocks are generally regarded as forming the base of the APAS, although exploration drilling at the Koeberg Nuclear Power Station (Murray and Saaiman, 2000) and in the Langebaan Road Aquifer System has indicated that it is not uncommon to intersect substantial yields (>10 L/s) of groundwater in the Malmesbury bedrock where it is overlain by thick, saturated Cenozoic sands. At places along the coast there is evidence of groundwater emerging from fractures in the bedrock and flowing into the sea (Visser, 1972).

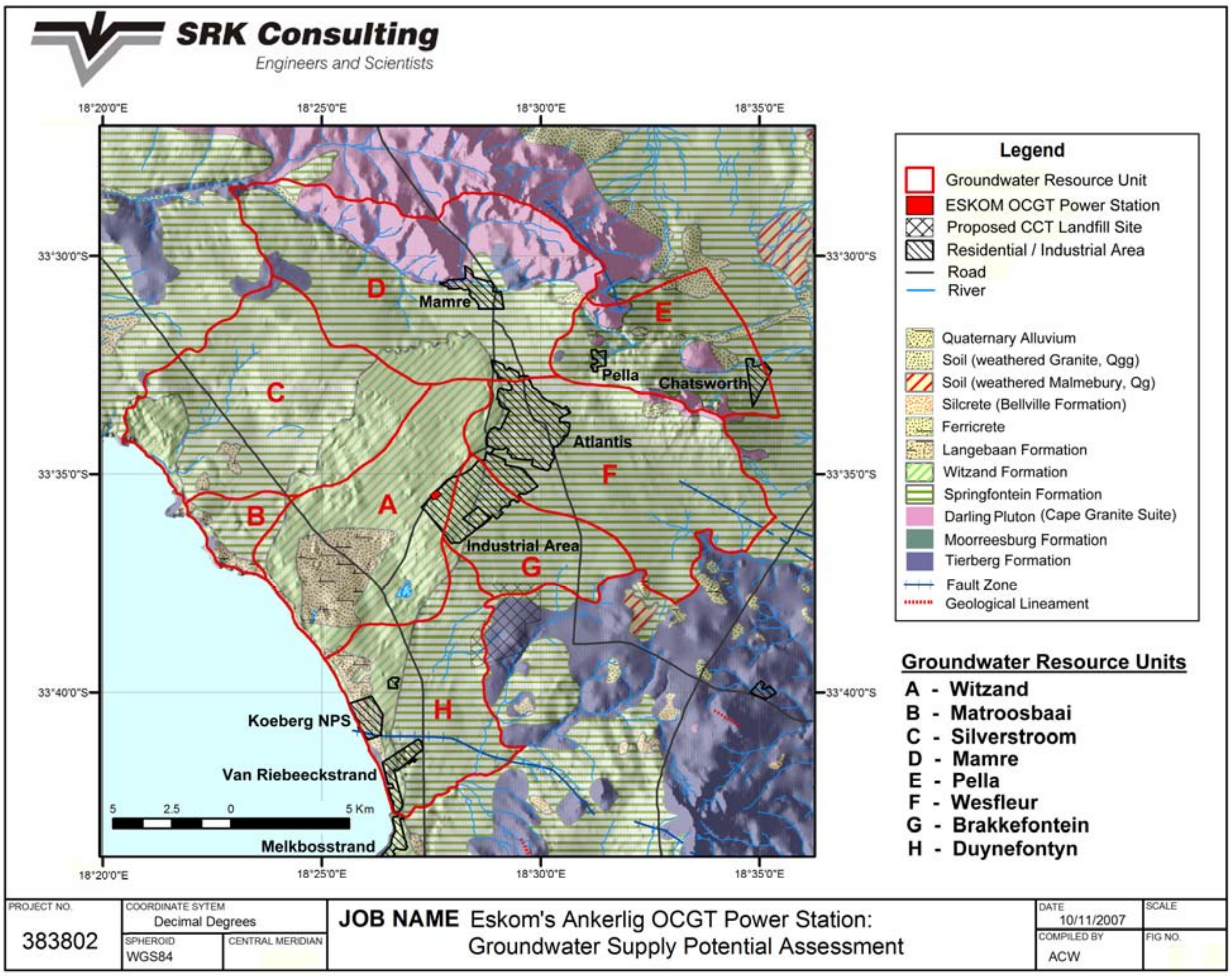

Figure 2: Geology of the Study Area showing Groundwater Resources Units

3 Work Program and Results

The project work comprised the following main tasks:

- Desktop study of all relevant geohydrological reports, maps and archived information (i.e. DWAF's National Groundwater Archive and water quality database, geological maps from the Council for Geosciences etc).
- Establishing a spatial database and carry out GIS analysis aimed at defining Groundwater Resource Units or GRU's;
- Assessing the broad characteristics (yield, water quality) of the various aquifers, and
- Determining the exploitation potential of these groundwater resources.
- Report writing.

3.1 Water Requirements of Ankerlig OCGT Power Station

ESKOM plans to expand and upgrade its Ankerlig OCGT power generation facility located in the Atlantis industrial area. ESKOM wish to increase the output capacity of the power station by constructing an additional five (5) units (**Figure 3**).

Information presented at a meeting between Savannah Environmental, Black & Veatch, SRK Consulting and ESKOM representatives on 28 August 2007, indicated that ~0.183 Mm^3/a or 500 m^3/day of water would be required if a zero-discharge cooling system is adopted, which would increase to 1.825 Mm^3/a or 5,000 m^3/day if a zero-discharge system is not adopted. It was stipulated that the water demand would remain constant throughout the year and that it would be utilised at the power station for processing and auxiliary cooling only.

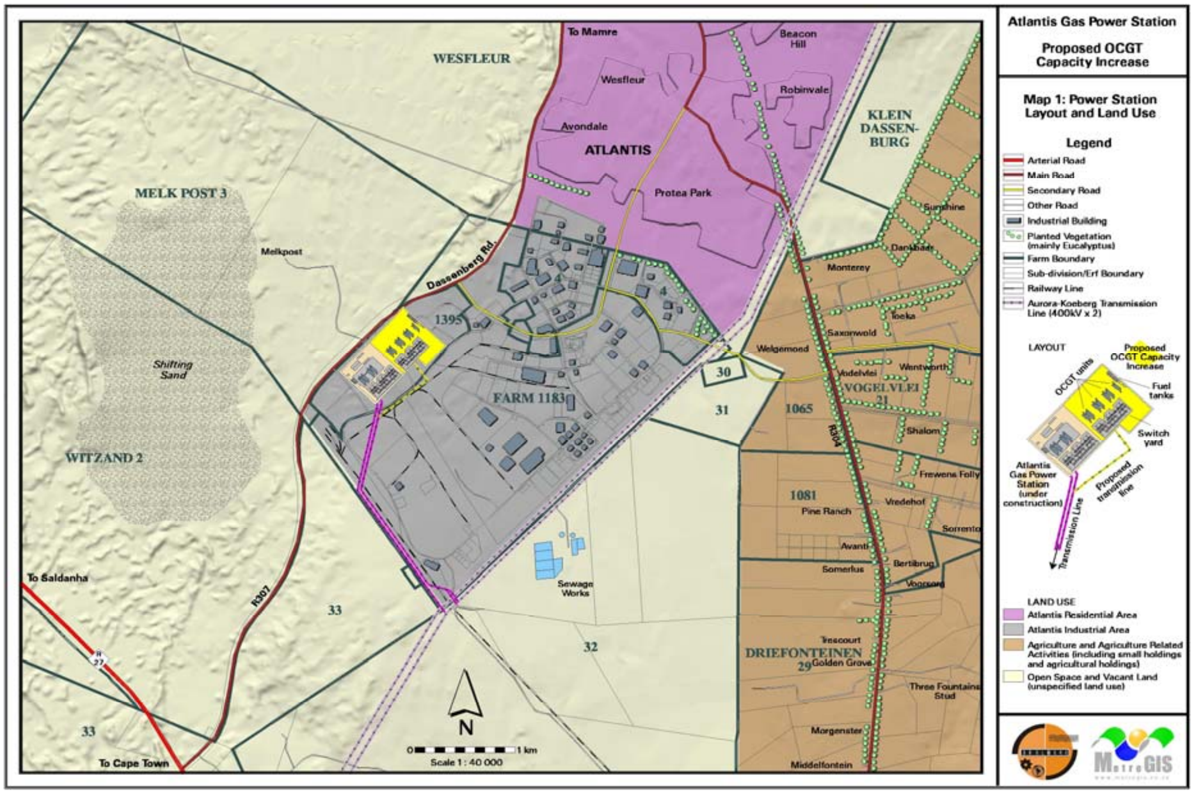

Figure 3: Location of Eskom's Ankerlig Gas Power Station showing proposed OGCT expansion

3.2 Previous Groundwater Supply Investigations at the Koeberg NPS

In 1995, the water requirement of the Koeberg Nuclear Power Station was ~130,000 m^3/month (Rosewarne, 1995). Since 1989, ESKOM has employed a number of consultants to develop a groundwater supply scheme on their property at Duynefontein. Rosewarne (1995) stated that none of these investigations were able to locate a viable groundwater resource capable of meeting the power stations water needs. At this time, SRK Consulting was appointed by ESKOM to carry out the following tasks:

- Summarise the results of all the previous geohydrological investigations;
- Investigate the possibility of obtaining water from the CCT's Witzand Wellfield; and
- Investigate the feasibility of developing a wellfield on ESKOM's property.

ESKOM owns two farms, one being Duynefontein on which the Koeberg Nuclear Power Station (KNPS) is located, and Kleine Springfontein which is located to the north of Duynefontein. Part of the APAS underlies Kleine Springfontein and under the terms of an agreement with ESKOM, the CCT developed the Witzand Wellfield which supplies Atlantis with part of its water requirements. In 1988, ESKOM purchased 1.92 Mm^3 of water form the Municipality. ESKOM embarked on a programme in 1989 to develop its own groundwater supplies so as to save on the high costs of purchasing water and because of its proximity to a known high-yielding aquifer system. ESKOM established a programme, the so-called 'Aquarius Project' with the stated aim, 'to investigate alternative sources of potable and irrigation water for the power station'. In 1989 SRK Consulting were awarded a contract to site, drill and test two production boreholes along the northern boundary of Duynefontein. Disappointing yields of 6 and 15m^3/hr were obtained from SRK1 and SRK2, respectively.

In December 1992, the CSIR were appointed to carry out a prefeasibility study on water supply to KNPS (Fleischer, 1992). The study identified five development options of which two were recommended for further investigation, namely the exploitation of the sand aquifer along the coastline near Koeberg and using treated domestic sewage water from Atlantis.

In February 1993, the CSIR conducted an investigation in which test wellpoints were installed along the Duynefontein coastline. Potential abstraction was estimated at 675,000 m^3/a, and it was recommended that four large diameter boreholes be sunk to further test the feasibility of groundwater abstraction. In August 1993, follow-up exploration drilling showed that the aquifer was too thin at this locality for abstraction via conventional boreholes and a system of horizontal drains with a central collector wells was proposed. Construction of the first system indicated that there was insufficient groundwater and the project was aborted.

In 1995, SRK Consulting was approached to develop a groundwater scheme that could supply a recently installed reverse-osmosis (RO) plant which had the capacity to process 50,000 m^3/month. SRK Consulting investigated two development options:

Groundwater from Kleine Springfontein

Two development options were assessed, namely to obtain a quota of water from the existing Witzand Wellfield, or to develop a new wellfield. Discussions with the CCT (then CMC) indicated that the Witzand Wellfield was considered to be over-exploited, mainly due to the fact that the production holes are concentrated in too small an area. One reason for this situation is the non-development of the nearby dune area for environmental reasons. Rosewarne (1995) reported that groundwater abstraction from the Witzand Wellfield had declined from 4.3 Mm^3 in 1992 to 3.5 Mm^3 in 1994. The reasons for this situation were given as, firstly increased pumping from the adjoining Silverstroom Wellfield and declining waterlevels in the Witzand Wellfield. To augment this declining water supply the Municipality constructed a pipeline linking into the Melkbosstrand reticulation system that received water from Voëlvlei Dam. The possibility of acquiring water from the Witzand Wellfield was therefore discounted.

The alternative option of ESKOM developing a new wellfield on Kleine Springfontein was restricted by the proximity of the property to the existing production boreholes in the Witzand Wellfield. Rosewarne (1995) indicated that the dune belt extending from the north of Duynefontein towards Kleine Springfontein was the only area suitable for development. Du Toit et al (1995) indicated that the thickness of the sands increase from 30m along the Duynefontein boundary to 40m in the centre of the dune area, and the saturated thickness is ~10m. Rosewarne (1995) recommended that five production boreholes, spaced ~1km apart, be developed assuming that each hole would be capable of delivery 5 L/s on a sustainable basis.

Du Toit et al (1995) conducted a feasibility study for the Koeberg Nuclear Power Station aimed at assessing the proposed impact of pumping 50,000 m^3/month of groundwater from a series of production holes located 1.5km to the south of the existing Witzand Wellfield. A numerical flow model was developed to asses the possible interference between the proposed abstraction scheme and the production holes in Witzand Wellfield, as well possible deterioration in water quality due to pumping. Natural recharge was assumed to be 42% and 23% of MAP for the exposed dune areas and vegetated areas, respectively. It was concluded that abstraction from the proposed ESKOM wellfield would not impact on the waterlevels in the Witzand Wellfield. The 'safe-yield' of the proposed wellfield was estimated to be ~500,000 m^3/a. The modelling indicated that the quality of the groundwater in the Witzand Wellfield, would actually improve as a result of pumping from the proposed wellfield.

Groundwater Consulting Services (GCS) were appointed by ESKOM to establish a wellfield to supply the Koeberg Nuclear Power Station with groundwater, as part of the 'Aquarius Project' (Jolly, 1996). In 1996, ten production boreholes were completed on Kleine Springfontyn to the northeast of the power station (**Figure 4**), which are capable of delivering 30.5 L/s. The long-term sustainable yield of the Aquarius Wellfield was estimated at 48,000 m^3/a (1,315 m^3/day).

3.3 Groundwater Resource Units

The study area extends over an area of ~340km^2 (**Table 2**) and it was subdivided into eight Groundwater Resource Units (GRU's) 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 deposits (**Figure 2**).

Table 2: Groundwater Resource Potential of the Study Area

Groundwater Resource Unit	Area (km^2)	MAP (mm)	Rainfall-Recharge Factor %	Mean Annual Recharge (m^3)	Average Groundwater Exploitation Potential (m^3/a)		Groundwater Harvest Potential (m^3/a)
					Normal	Drought	
Witzand (A)	49.40	483	16	3,817,600	1,447,000	968,700	3,010,900
Matroosbaai (B)	7.63	409	18	562,000	168,600	113,300	475,350
Silverstroom (C)	60.46	459	17	4,717,700	1,095,00	740,000	3,130,00
Mamre (D)	74.11	558	16	6,616,500	967,100	667,800	1,873,400
Pella (E)	30.95	603	13	2,426,200	365,100	270,000	874,100
Wesfleur (F)	58.75	544	13	4,154,800	1,344,000	1,025,400	1,200,000
Brakkefontein (G)	22.03	503	15	1,662,200	541,700	374,100	1,122,600
Duynefontein (H)	38.74	489	15	2,841,600	768,300	523,300	2,413,500
TOTAL (Mean)	**342.07**	**(506)**	**(15.4)**	**26,798,600**	**6,696,800**	**4,682,600**	**11,283,000**
Notes: Mean Annual Precipitation (MAP) - CCWR Schultze (1997)							

3.4 Description of the Aquifer Systems with the GRU's

The DWAF's 1/500 000 scale National Hydrogeological mapsheets are used as a basis for broadly defining the types of aquifers present within each of the GRU's, as well as to obtain an idea of likely borehole yields and water quality variations within each unit.

3.4.1 Witzand Groundwater Resource Unit

The Witzand Groundwater Resource Unit cover an area of ~49km^2 (**Table 2**), and comprises of calcareous dune sand of the Langebaan and Witzand Formations. The Witzand sands form the extensive dune belt which covers a large area of unit. These dunes are important from an aquifer recharge point of view. ESKOM's Ankerlig OCGT Power Station is located in the north-eastern portion of this unit, close to the boundary with the adjoining Brakkefontein GRU.

The Witzand GRU lies at the centre of the Atlantis Primary Aquifer System, where average borehole yields are expected to range between 2 and 5 L/s (**Figure 4**), except in the most productive zone located in the south-eastern portion of the unit, where yields in excess of 5 L/s are common. Bertram et al (1983) state that exploration drilling indicates that production boreholes with yields of 15 L/s can only be developed in this specific section of the Witzand GRU, which they referred to as the 'Witzand Production Element'. The CCT's Witzand Wellfield is located in this zone. They state that lower permeability sediments surround this 'element' resulting in significantly lower borehole yields. Note that the productive zone extends across the GRU boundary into the Duynefontein Unit, where ESKOM developed the Aquarius Wellfield aimed at supplying water to its Koeberg Nuclear Power Station (NPS). This wellfield is currently not being utilised because of water quality considerations.

The lithological composition of the sediments making up the primary aquifer varies over short distances, but the Springfontyn deposits are by far the most permeable of the units, followed by those of the Duynefontyn Member, whilst the Silverstroom Member is made up of low permeability fine-grained sediments. Although the permeabilities of the sands in the Silverstroom Wellfield are generally higher than those in the Witzand GRU, the transmissivity of the latter unit is higher due to its greater saturated thickness (Bredenkamp and Vandoolaeghe, 1982).

In the Witzand Wellfield the aquifer consists of two main hydrogeological units, namely (i) an upper 10m thick succession of fine-grained sands of the Witzand Formation, which is (ii) underlain by the Springfontyn Formation. In this area, the upper facies of the Springfontyn Member consists of fine-grained sand, which grades downwards into medium- to coarse-grained sand just above the Malmesbury bedrock situated at a depth of ~20m below surface.

Groundwater flows directly from the north-eastern portion of the GRU in a south-easterly direction towards the coastline where it discharges into the Atlantic Ocean. The quality of the groundwater in the central portion of the unit is relatively good (electrical conductivities or EC are < 70 mS/m, **Figure 5**), whilst salinity increases towards the edge of the GRU (EC's range between 70 to 300 mS/m). The groundwater is generally hard and at places contains significant amounts of iron. The production capacity of the Witzand Wellfield has declined over the years due to increased activity of slime-forming bacteria in the groundwater which gradually clog up the borehole screens, pumps and the aquifer material in the vicinity of production boreholes.

During 2005, the CCT abstracted ~3,17 Mm^3 of groundwater from the Witzand Wellfield (**Table 3**), which is similar to the quantity abstracted in 1994.

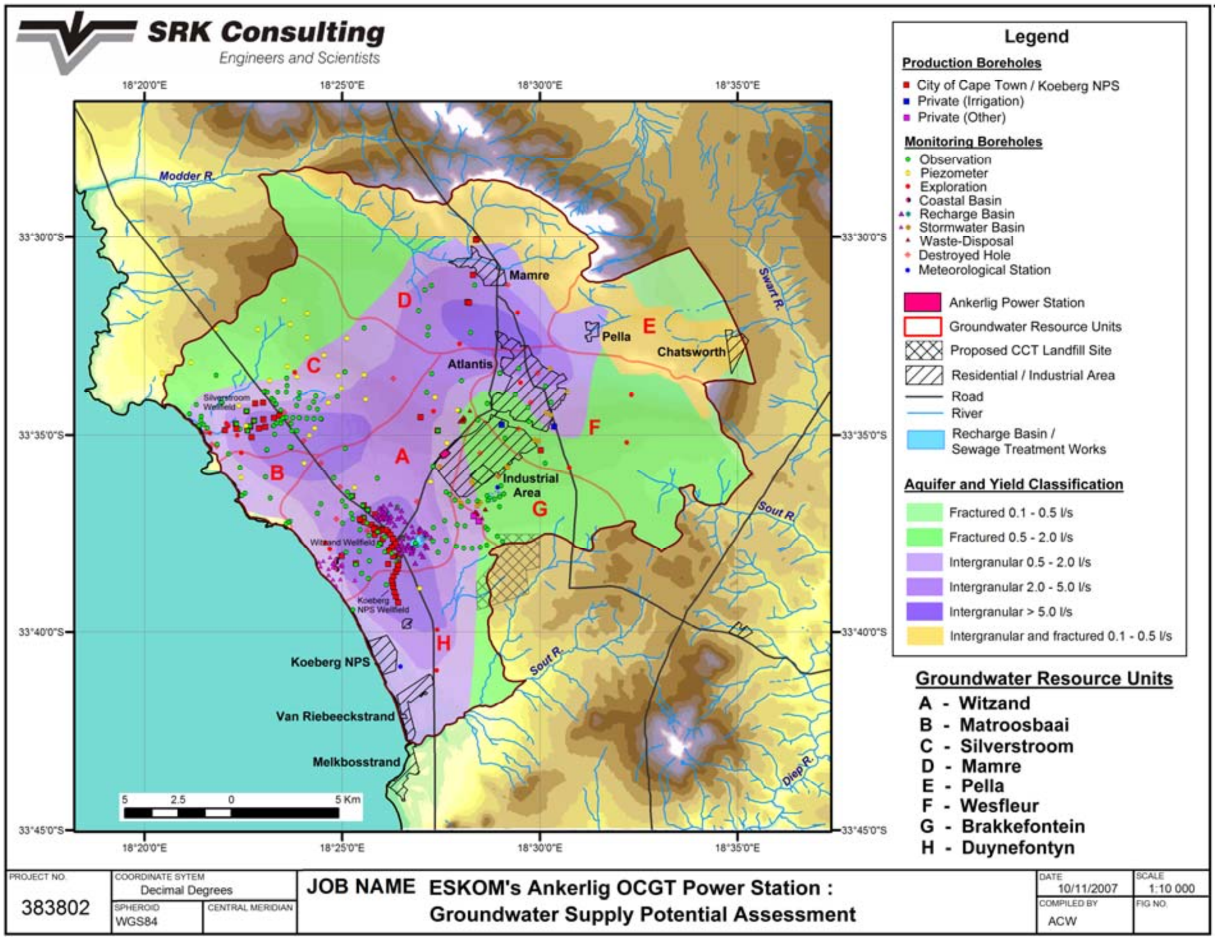

Figure 4: Aquifer and Borehole Yield Classification for the Study Area

Table 3: Groundwater Abstraction from the Witzand Wellfield in 2005

Month	Volume Abstracted (m^3)
Jan-2005	314,370
Feb-2005	258,010
Mar-2005	290,090
Apr-2005	337,250
May-2005	284,880
Jun-2005	302,220
Jul-2005	210,790
Aug-2005	145,110
Sep-2005	231,430
Oct-2005	224,340
Nov-2005	256,340
Dec-2005	314,490
Total	**3,169,320**
Average	264,110
Source: Mr. R. Bishop (2007)	

3.4.2 Silverstroom and Matroosbaai Groundwater Resource Unit

The Silverstroom and Matroosbaai Units have traditionally been considered together due to their similar hydrogeology (Bredenkamp and Vandoolaeghe 1982), and together they cover an area of ~68 km^2 (**Table 2**). The Matroosbaai GRU is defined by a separate palaeo-channel that is incised into the Malmesbury bedrock. Sands of the Springfontein Formation cover most of the GRU, except along the coastline and the eastern boundary with the Witzand GRU where the Witzand Formation occurs (**Figure 2**). An outcrop of Tierberg shale along the coastline of the Matroosbaai unit restricts the discharge of groundwater into the sea.

Saturated sands overlying the Malmesbury bedrock in these units form the extensive Atlantis Primary Aquifer System (**Figure 4**). The thickness of the aquifer is highly variable, but reaches a maximum of 50m in the south-western portion of the Silverstroom GRU. Boreholes tapping this aquifer generally yield between 0.5 and 5.0 L/s, except towards the south-western portion of the GRU where yields in excess of 7 L/s are not uncommon. The City of Cape Town's Silverstroom Wellfield is located in this highly productive aquifer zone. The hydraulic properties of the sediments away from the main Silverstroom production zone are markedly lower. The north-western half of the Silverstroom GRU is covered by a thin layer of sand and groundwater is intercepted in fractures within the underlying Tierberg shale. Borehole yields in this area are generally low (0.5 to 2.0 L/s).

Groundwater flows from the north-eastern, high-lying parts of the unit, in a south-westerly direction towards the coastline, where it probably discharges below sea-level into the Atlantic Ocean. The quality of the groundwater is variable. According to the DWAF's 1/500,000 scale National Hydrogeological coverage, the electrical conductivity of the water generally varies between 70 to 300 mS/m. The production capacity of the CCT's Silverstroom Wellfield has declined over the years due to bio-fouling of the production holes by the activity of Fe-bacteria in the groundwater. The groundwater along the coastal boundary of the Matroosbaai GRU is brackish (EC >300 mS/m).

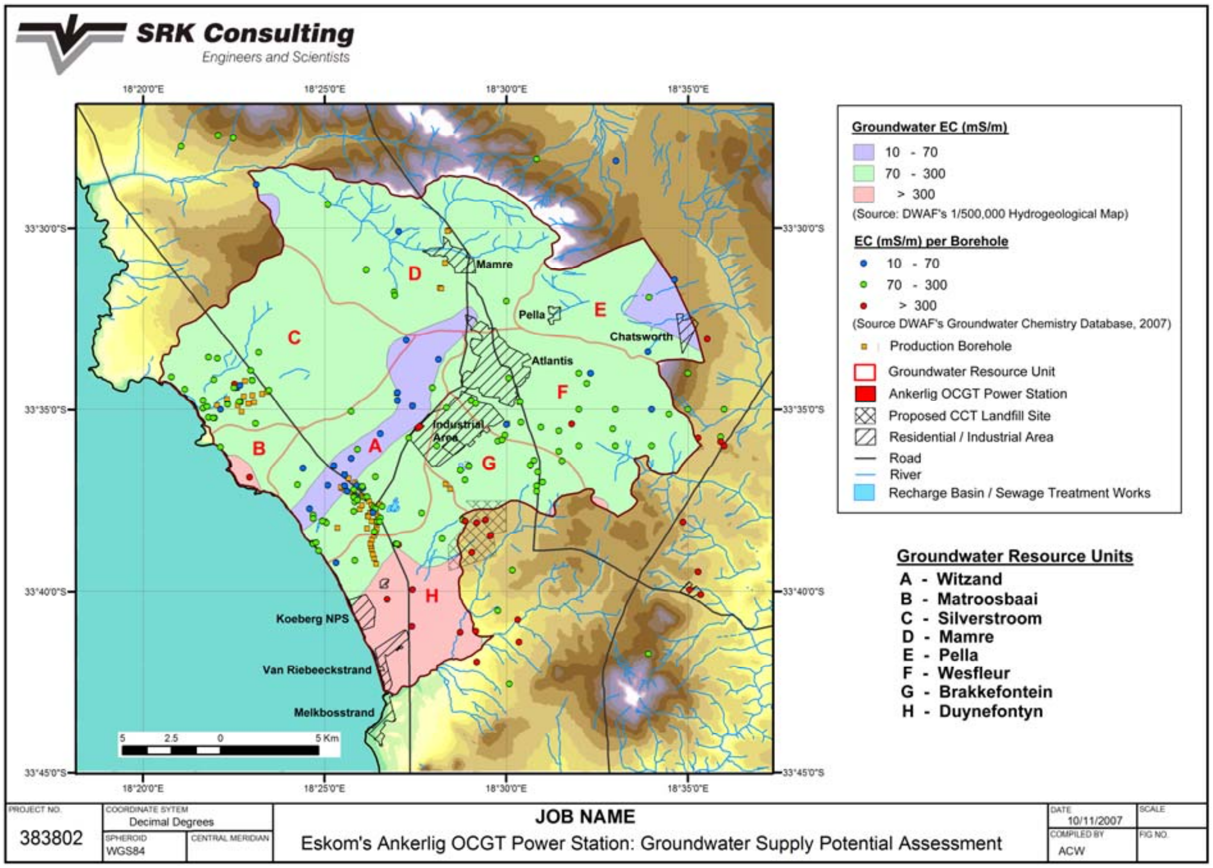

Figure 5: Groundwater Salinity (Electrical Conductivity) in the Study Area

3.4.3 Mamre Groundwater Resource Unit

The Mamre Groundwater Resource Unit (GRU) is formed by the catchment of a tributary of the north-westerly to westerly flowing Modder River (**Figure 1**) and covers an area of 74 km^2 (**Table 2**). Fine-grained sediments of the Springfontein Formation cover the relatively flat-lying area to the south of the Modder River, whilst granite of the Darling Pluton forms the high-lying ground (Dassenberg) to the north of the River (**Figure 2**). The river flows along the contact between the Tierberg shale and the intrusive granite. The linear, north-westerly trend of the river indicates that this contact zone may be fault controlled.

Saturated Cenozoic sands between Mamre and Atlantis form the northern extremity of the Atlantis Primary Aquifer System, where borehole yields of 2 to 5 L/s are common (**Figure 4**). Borehole yields in excess of 5 L/s can be obtained in the more permeable zone just to the north of Atlantis. The town of Mamre uses groundwater from this aquifer. Boreholes drilled into the weathered granites to the north of the Modder River are generally low yielding (< 0.5 L/s). In the north-western portion of the unit, moderate borehole yields (<2.0 L/s) are intercepted in the weathered / fractured Tierberg shale located to the south of the Modder River.

Groundwater is likely to drain from the higher-lying ground along the edges of the GRU towards the Modder River in the centre of the unit. The quality of the groundwater is moderate to good, with EC's commonly ranging between 70 and 300 mS/m (**Figure 5**).

3.4.4 Pella Groundwater Resource Unit

The Pella Groundwater Resource Unit extends over an area of 31 km^2 (**Figure 1, Table 2**) and is bounded to the north-west and south by the Dassenberg and Kanonkop Mountains, respectively. The eastern boundary of the GRU is formed by the prescribed 15km distance limit from the Ankerlig Power Station (i.e. at Chatsworth). The unit is drained by an easterly flowing tributary of the Swart River. The low-lying areas are covered by sediments of the Springfontein Formation, whilst granites of the Darling Pluton form the surrounding hills (**Figure 2**). Boreholes in this unit are generally low-yielding (0.5 L/s, **Figure 4**) with the exception of a small area to the west of Pella where borehole yields of ~2 L/s are not uncommon. The relatively low-yielding capacity of aquifers in this GRU is ascribed to the absence of extensive, saturated Cenozoic sands and the weakly fractured nature of the underlying Tierberg shale and granite. It is anticipated that groundwater in the high-lying, western portion of the unit (at Pella) will drain relatively quickly across the eastern boundary of the unit, and on towards the Swart River. The quality of the groundwater in this GRU is moderate to good. The electrical conductivity of the groundwater varies between 70 to 300 mS/m over most of the Unit (**Figure 5**), except in the east (near Chatsworth) where the EC is generally < 70 mS/m. This GRU will not be given any further attention due to the expected low-yielding capacity of its aquifer systems.

3.4.5 Wesfleur Groundwater Resource Unit

The town of Atlantis is located in the 'headwaters' of the Wesfleur GRU that covers an area of ~60 km^2 (**Table 2**). In this area, the boundary between the Wesfleur and Brakkefontein units is primarily defined by a distinct topographic-high in the bedrock underlying the Cenozoic deposits, and to a lesser extent by the surface water drainage system.

The unit is almost entirely covered by unconsolidated sediments of the Springfontein Formation. The GRU is bounded in the south-east by outcropping shale of the Tierberg Formation (**Figure 2**). The majority of the unit are underlain by moderate to low-yielding, fractured-rock aquifers (**Figure 4**), where borehole yields of <2.0 L/s is expected. However, isolated moderate to high-yielding boreholes can be expected in the fractured Malmesbury bedrock extending in a zone along the north-west trending fault system. Relatively high-yielding (2.0 to 5.0 L/s) boreholes tap the saturated Cenozoic sands located in and around Atlantis. However, this groundwater apparently flows directly southwards across the boundary into the Brakkefontein GRU.

The quality of the groundwater in the GRU is variable, with EC's ranging between 70 and 300 mS/m (**Figure 5**). Groundwater EC's in excess of 300 mS/m are likely to be encountered in the fractured bedrock in the south-eastern portion of the unit. It is also likely that the groundwater in the vicinity of Atlantis will be contaminated as a result of various anthropogenic activities.

3.4.6 Brakkefontein Groundwater Resource Unit

The Brakkefontein Groundwater Resource Unit extends over an area of 22 km^2 (**Table 2**) and is almost entirely covered by unconsolidated sediments of the Springfontein Formation (**Figure 2**). The GRU is mainly defined by a south-easterly trending palaeo-channel that has been incised into the Tierberg bedrock. The south-eastern boundary of the unit is formed by outcrops of Tierberg shale. The CCT propose to develop a regional landfill site between this boundary and the Donkergat River

(**Figure 1**) The Atlantis industrial area lies in the 'headwaters' of the Brakkefontein GRU, as does the sewage treatment works and the Atlantis Diesel Electric (ADE) waste-disposal site.

The Brakkefontein GRU is mostly underlain by localised, secondary aquifers developed in the weathered and fractured Tierberg shale, where borehole yields are likely to be moderately low (< 2.0 L/s, **Figure 4**). Saturated Cenozoic sediments occur along the western and north-western boundary of the unit where borehole yields in the order of 2 L/s can possibly be developed.

The quality of the groundwater in the GRU is variable, with EC's ranging between 70 and 300 mS/m (**Figure 5**). It is likely that the groundwater will be contaminated by various activities taking place in the industrial area. Groundwater EC's in excess of 300 mS/m are likely in the fractured bedrock in the south-east part of the unit.

3.4.7 Duynefontyn Groundwater Resource Unit

The Duynefontyn Groundwater Resource Unit extends from the edge of the Atlantis industrial area southwards to the Sout River near Van Riebeeckstrand (**Figure 1**). The western and the eastern boundaries of the GRU are formed by the coastline and the Tierberg rocks (**Figure 2**), respectively. ESKOM's Koeberg nuclear power station is located in this unit. The GRU extends over an area of ~40 km^2 and is mostly covered by sediments of the Witzand and Springfontein Formations (**Table 1**).

The thickness of the Cenozoic sands decreases southwards from 30 to 40m at the boundary of the Witzand GRU to 15 to 20m at the Koeberg Nuclear Power Station. These deposits form the southernmost extension of the Atlantis Primary Aquifer System. The CCT's Witzand Wellfield is located in the most productive portion of the aquifer (**Figure 4**), which lies just to the north of the Duynefontyn - Witzand boundary. Boreholes in the Witzand Wellfield generally yield in excess of 10 L/s. The transmissivity of the aquifer decreases rapidly towards the south due to an increase in the percentage of finer material and a decrease in the saturated thickness of the sands. Borehole yields in the range of 0.5 to 5 L/s are therefore common in the sands underlying the Duynefontyn 34 cadastral unit, on which the Koeberg NPS is located. The 1/250,000 scale geological mapsheet (3318) shows the so-called 'Milnerton' lineament (fault?) passing through the southern portion of the GRU. Groundwater in the primary aquifer flows under a relatively low gradient from north-east towards the coastline. The quality of the groundwater is variable, with EC's generally varying between 70 and 300 mS/m in the northern extremities of the GRU, whilst to the south of this zone the EC's often exceed 300 mS/m.

3.5 Groundwater Resource Potential

This part of the study makes extensive use of the DWAF's National Groundwater Resources Assessment Phase II (GRAII, 2007) 1 x 1km raster datasets in order provide preliminary estimates of the exploitation potential of the GRU's in the study area.

3.5.1 Atlantis Primary Aquifer System

Aquifer Storage

Bredenkamp and Vandoolaeghe (1982) provide estimates of the volumes of groundwater stored in the Atlantis Primary Aquifer System (APAS) prior to commencement of large scale abstraction (**Table 4)**. They also provide estimates of the volumes of groundwater that can be 'safely mined' from the various GRU's without causing seawater intrusion into the aquifer, and assuming that the production boreholes are not located close to the coastline. Bredenkamp and Vandoolaeghe point out that only a small proportion of this groundwater is stored below mean sea-level.

Bredenkamp and Vandoolaeghe (1982) state the Witzand and Silverstroom GRU's are in direct hydraulic connection with one another and that groundwater can flow freely between these two units, implying that a certain proportion of the water stored in one unit can be abstracted indirectly from the other unit. This is also the case, but to a much lesser extent, between the Silverstroom and Matroosbaai Units, as well as between the Witzand and Brakkefontein GRU's. They state that this does not fully apply to the Witzand and Wesfleur Units, where groundwater can only flow from the Wesfleur to the Witzand aquifer.

Table 4: Estimated Volumes of Groundwater Stored in the Atlantis Primary Aquifer System

Groundwater Resource Unit	Area (km^2)	Volume Groundwater in Storage (x 10^6 m^3)	
		Total	Abstractable
Silverstroom	52.6	71	50
Witzand	44.8	189	130
Wesfleur	36.5	79	55*
TOTAL	**-**	**339**	**235**

Source: Bredenkamp and Vandoolaeghe (1983)
Note: The Matroosbaai GRU has been included in the Silverstroom Unit.
The extend / boundary of the Witzand GRU towards Melkbosstrand is unknown and was estimated.
* - boundary condition are unkown

Rainfall Recharge

Bredenkamp and Vandoolaeghe (1982) derived a recharge factor for the Silverstroom GRU of 25% of MAP (390mm) by using a water-balance approach to analyse groundwater monitoring information collected between 1978 and March 1982. This equates to a mean annual recharge of 5.32 Mm^3. They applied this recharge factor to the Witzand and Wesfleur GRU's and obtained estimates of mean annual recharge of 4.39 and 3.79 Mm^3/a, respectively.

The GRAII dataset provides an 'average" rainfall-recharge factor for the entire study area of 15.4% using the Chloride Mass Balance (CMB) approach. This factor is substantially lower than that obtained by Bredenkamp and Vandoolaeghe (1982) but the GRAII estimates are accepted for this preliminary study, purely because they are more conservative. The total volume of rainfall recharge in the study area is therefore estimated at ~26.8 Mm^3/annum. The total annual volumes of rainfall recharge per groundwater management unit are presented in **Table 2**.

Long-term Assured Yield

Bredenkamp and Vandoolaeghe (1982) estimated the long-term assured yield of the Atlantis Primary Aquifer System, as defined by the geographic extent of the Silverstroom, Matroosbaai, Witzand and Wesfleur GRU's, at between 10.8 to 12.2 Mm^3/a. They estimated the yield potential of APAS at 14 Mm^3/a if both the rainfall recharge and the 'abstractable' portion of groundwater held in storage are taken into account.

3.5.2 Groundwater Exploitation Potential and DWAF's General Authorisation Limits

The DWAF's GRAII 'Average Groundwater Exploitation Potential' or AGEP dataset is used to estimate the long-term sustainable yield of each GRU in the study area for periods of normal rainfall (i.e. mean annual precipitation), as well as droughts. These estimates are presented in **Table 2**. The DWAF's national 'Groundwater Harvest Potential' (Baron et al, 1998) estimates are also presented for comparative purposes. The long-term sustainable yield of all the aquifer systems in the study area is estimated at 6.7 Mm^3/a during periods of normal rainfall, declining to 4.7 Mm^3/a during prolonged droughts. These estimates are accepted, albeit that they may be conservative, as they represent the most recent available information on the groundwater resource potential of the region, despite the fact that they are less than half of the 'Harvest Potential' estimates.

During 2005, the CCT abstracted 3.17 Mm^3 from the Witzand Wellfield (**Table 3**), which is just over double the AGEP of the entire GRU during periods of normal rainfall and is just about equal to Harvest Potential (**Table 2**).

The DWAF make use of the 'General Authorisation' (GA) of the National Water Act as a guideline when considering an application to utilise a groundwater resource within a particular Quaternary catchment. Application for groundwater abstraction volumes in excess of the GA will require 'licensing' by the DWAF, which normally entails a detailed hydrogeological investigation of the entire aquifer system aimed at determining the 'Groundwater Reserve', as well as a basic environmental impact assessment (EIA). The 'Groundwater Reserve' includes the water requirements of the environment, which must first to be satisfied before water can be allocated for other purposes (i.e. irrigation).

Note that *Activity No. 13 of the activities identified in terms of Section 24(2)(a) and (d) of the National Environmental Act, 1998 (Act No. 107 of 1998), which may not commence without environmental authorisation from the competent authority and in respect of which the investigation, assessment and communication of potential impact of activities must follow the procedure as described in regulations 22 to 26 of the Environmental Impact Assessment Regulations, 2006 promulgated in terms of Section 24(5) states that the abstraction of groundwater at a volume where any general authorisation issued in terms of the National Water Act, 1998 (Act No. 36 of 1998) will be exceeded.*

The study area falls within portions of Quaternary drainage regions G21A, G21B and G21D (**Figure 1**), and therefore falls within Groundwater Abstraction Zones A and D as stipulated in the revised (Government Gazette 26187, No. 399, 20 March 2004) General Authorisation (GA) of Section 39 of the National Water Act #36 (1998). This only allows for the abstraction of 150 m^3/annum per hectare from Zone D and zero for Zone A (**Table 5**). In other words, any application to the DWAF to utilise groundwater in Zone A will require full licensing as described above. Only the Pella and southern half the Wesfleur GRU's fall into Zone D, whilst the remaining units all fall within Groundwater Zone A.

Table 5: General Authorisation for Quaternary Catchments

Quaternary Catchment	Groundwater Zone	General Authorisation Abstraction Limit (m^3/ha/a)	Special Provisions
G21A	A	0	Only Schedule 1 use (~10m^3/day), Small industrial use.
G21B	A	0	Only Schedule 1 use (~10m^3/day), Small industrial use.
G21D	D	150	Small industrial use.

4 Conclusions and Recommendations

The proposed expansion and upgrading of ESKOM's Ankerlig Open Cycle Gas Turbine (OCGT) power generation facility in Atlantis will require good quality water for processing and auxiliary cooling in the order of 500 m^3/day (0.183 Mm^3/a) if a zero-discharge system is adopted, increasing to 5000 m^3/day (1.825 Mm^3/a) if such a system is not implemented. The following conclusions are made in terms of meeting these water requirements from groundwater resources located within a 15km radius of the power station:

- Atlantis Primary Aquifer System (APAS) is the important groundwater resource in the study area:
  - The APAS extends over the entire Witzand and Matroosbaai Groundwater Resource Units, as well as large parts of the Silverstroom, Mamre and Duynefontein Units; and a smaller portion of the Wesfleur GRU.
  - The APAS is capable of yielding a minimum of ~4Mm^3/a of groundwater on a sustainable basis. This figure may be as high as ~9Mm^3/a if the less conservative 'Harvest Potential' estimate is accepted.
  - It is relatively easy to develop moderate- to high-yielding (5 to 15 L/s) boreholes within specific zones of the APAS, if the correct drilling and construction techniques are applied.
  - The quality of groundwater in the APAS is generally moderate to good, with EC's of <300 mS/m. The water is often very hard and contains appreciable quantities of dissolved iron and manganese.
  - Production boreholes in the APAS are prone to clogging by slime-forming aerobic and anaerobic bacteria in the groundwater, especially if they are over-exploited. Bio-fouling gradually reduces the yield of production boreholes if they are not regularly treated and rehabilitated.
  - The Witzand and possibly the Silverstroom GRU's are currently being fully exploited. The bulk of the groundwater is being abstracted by the City of Cape Town's two wellfields. As far as could be ascertained, there may be 'spare' capacity for the development of additional production holes in those parts of the APAS that straddle the Brakkefontein and Duynefontein GRU's.
- Localised, secondary aquifer systems are present throughout the study area in fractured shale and greywackes of the Tierberg Formation, as well as weathered and jointed granites. In most areas, however, such boreholes are likely to be low-yielding (< 2 L/s). Groundwater in the Tierberg shale is also likely to be brackish (EC > 300 mS/m). Relatively high-yielding boreholes can occasionally be developed in well fractured (faulted) bedrock underlying the APAS, where the saturated thickness of the sands exceeds 10m, but where its permeability is too low to be tapped directly using standard boreholes.
- All the GRU's in the study area, with the exception of the Pella and parts of the Wesfleur Units, fall within Zone A of the revised General Authorisation (2004) of Section 39 of the National Water Act (1998), where only Schedule 1 and small-scale industrial use will be granted without the need to follow the time consuming and costly licensing procedure.

The following specific recommendations are made based upon the findings of this study:

- If ESKOM adopts a zero-discharge system and its water requirements are ~500 m^3/day it is recommended that the following options should be investigated:
  - The feasibility of developing a wellfield in the APAS (Witzand GRU) about 1 to 2 km due west and/or south-west of the power station; or
  - Developing a wellfield in the APAS (Brakkefontein GRU), some 3.5km southeast of the power station and just south of the sewage treatments works, where previous drilling has indicated the presence of an incised paleo-channel in the underlying bedrock. The water-bearing capacity of the bedrock should also be tested at this site.
  - Purchasing treated waste-water from the sewage treatments works.

Development of a wellfield in the Witzand GRU is favoured over that of the Brakkefontein GRU because of borehole yield and water quality considerations, as well as its proximity to the Ankerlig Power Station. Both options will require full licensing with the DWAF.

- If ESKOM does not adopt a zero-discharge system and their water requirements are significantly higher, in the order of 5,000 m^3/day, the following options, beside those already listed above, should be further investigated in the following order of priority:
  - Negotiating with the CCT to purchase groundwater from their Witzand and/or Silverstroom Wellfields. Both wellfields are not currently operating at their full capacity due to declining borehole yields associated with bio-fouling of the screens and pumps. ESKOM could offer to rehabilitate a number of production boreholes that are currently out production due to severe clogging.
  - The feasibility of utilising ESKOM's existing relatively high-yielding boreholes in the Aquarius Wellfield. The sustainable yield of this wellfield is ~48,000 m^3/a. This would include the development of additional production boreholes in the northernmost portions of the Brakkefontein GRU (i.e. on the farm Brakkefontein). Geophysical surveys should also be conducted to locate laterally extensive, NW-striking fracture zones in the underlying bedrock with the aim establishing production holes that draw water from open fractures that drain the overlying saturated sands.
  - The groundwater yielding potential of NW-trending lineament (fault) passing through the centre of the Wesfleur GRU should be investigated, especially along its extension beneath the APAS just to the north of Atlantis. The north-westerly extension of this lineament into the Mamre Unit should also be investigated, especially along the Modder River where it follows the contact between the Malmesbury shale and the Cape granite. Relatively high-yielding (5 to 10 L/s) boreholes are known to occur elsewhere, under similar geological settings.

It is unlikely that ESKOM will be able to meet its water requirements of 1.825 Mm^3/a from any one the above groundwater development options.

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