ESKOM HOLDINGS LIMITED
GENERATION DIVISION

NUCLEAR 1 ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAMME

SPECIALIST STUDY FOR SCOPING REPORT

SPECIALIST STUDY: GEOTECHNICS

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Glossary of Terms

Aeolian: Deposited by wind.

Amphibolite: A metamorphic rock composed mostly of amphibole minerals.

Bearing Capacity: The carrying capacity of soil/rock materials as an indicator of what loads can safely be placed on such materials.

Caisson: A chamber, usually of steel but sometimes of wood or reinforced concrete, used in the construction of foundations.

Consistency of Material: The degree to which soil materials have consolidated.

Dispersivity: A property of an aquifer which takes into account the dispersion of particles.

Geotechnical Characterization: Three dimensional description of the subsurface rocks and soils encountered at the site and prediction of how these will behave under induced loads (i.e. when the project is physically developed).

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.

Interbedded: Beds (layers) of rock lying between or alternating with beds of a different kind of rock

Neutral Equilibrium: A body is in neutral equilibrium if it stays in the displaced position after if has been displaced slightly.

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.

Piles: Structures used to transfer loads through zones of poor geotechnical properties to zones of good/better geotechnical properties at greater depth.

Proposed Project Footprint: That area, and the spatial definition of that area, where the project will be superimposed on the natural and/or social environment.

Rankine Earth Pressure: Lateral earth pressure that increases in simple proportion (linearly) to depth.

Semi-consolidated: Soils that have partially undergone a process of natural settlement with time.

Slickensides: Polished, grooved surfaces that occur along shear planes within the soil.

Stratigraphic: Rock layers and layering.

Surficial Horizons: Soil layers containing unconsolidated sediments.

Transmissivity: The volume of water flowing through a unit cross-sectional area of an aquifer of unit aquifer thickness under a unit hydraulic gradient in a given amount of time.

Unconsolidated: soils that have not yet undergone a process of natural settlement with time.

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.

Weathering: The decomposing of rocks/soils and their minerals through direct contact with the elements (air, water etc)

List of Abbreviations

EIA	Environmental Impact Assessment
NNRA	The National Nuclear Regulator Act
NEMA	The National Environmental Management Act

1 EXECUTIVE SUMMARY

Eskom Holdings Limited (Eskom) is proposing to construct a Nuclear Power Station and associated infrastructure, either in the Eastern, Northern or Western Cape Province.

Under the auspices of the Eskom Nuclear Site Investigation project, lead by a team of independent consultants, numerous sites along the South African coastline were previously investigated. Based on various social, economic and environmental criteria the following potential sites were identified:

- Bantamsklip (Western Cape – 10km south east of Pearly Beach)
- Brazil (Northern Cape – Kleinsee/Port Nolloth area)
- Duynefontein (Western Cape – adjacent to the existing Koeberg Power Station, Cape Town)
- Schulpfontein (Northern Cape – Hondeklipbaai/Kleinsee area)
- Thyspunt (Eastern Cape – West of Port Elizabeth near Cape St Francis)

The current phase of the choice of a suitable site for the first new-generation nuclear power station, involves the Environmental Impact Assessment (EIA) phase, under which numerous physical, biophysical, oceanological and engineering aspects are being investigated. This report considers the Geotechnical Engineering aspects of the sites. The report is preliminary and based on a desk study of the information available at present. Further in-depth studies will be required before further evaluations can be completed.

The initial conclusions and characteristics of the 5 sites can be summarised as follows:

- The Thyspunt and Bantamsklip sites have some similarities with regard to the sand dune overburden (4 to 20m thick) overlying saw-toothed erosion gullies in the bedrock. These sites are categorised geotechnically as good to poor but variable. Besides down graded bearing capacity due to the variability, erosion and slope stability could be problematic and must be engineering carefully.
- The Duynefontein site (Koeberg) is characterised by thick horizons of variably consolidated sands up to 19m thick overlying variably weathered Malmesbury Group shales, mudstones and greywackes. The founding conditions are considered to be medium to good notwithstanding that the base rock may be weathered in places. The groundwater is at about 7m below surface and hence will have a considerable influence on geotechnical structures and require dewatering and permanent protection measures. Also, the liquefaction potential is significantly higher on this site compared to the other proposed sites. Historically, soil boils and surface cracking have been recorded under seismic conditions in the Cape Town areas.
- The Brazil and Schulpfontein sites are characteristically similar albeit that they are located on different base rock types. The overburden sand, calcrete with boulders and cobbles are in general 2 to 6m thick and should not cause geotechnical problems. The underlying bedrock of granite and gneiss/quartzite, respectively, are competent and relatively uniform thus leading to the conclusion of excellent founding conditions. Some caution must be exercised with regard to preferential weathering of amphibolite (granite) and sugary gneiss/quartzite on the sites, respectively. Groundwater is unlikely to pose a problem and erosion is likely to be minor, but must be controlled by judicious design.

2 INTRODUCTION

2.1 Description of Proposed Project

Eskom is proposing to construct a Nuclear Power Station and associated infrastructure, either in the Eastern, Northern or Western Cape Province. This is due to South Africa’s rapidly growing electricity demand, which requires Eskom to expand its electricity generating capacity.

Based on current planning, Eskom needs to increase its generating capacity by more than 40,000 megawatts of electricity over the next 20 years. This additional generating capacity could come from a variety of energy sources, for example, coal, liquid fuels, gas turbines, natural gas, hydro and pumped storage schemes, wind and solar energy and uranium (nuclear).

In order to meet the required generation capacity, Eskom is investigating the construction of a Nuclear Power Station and associated infrastructure. In the early 1980s, Eskom considered it prudent to commission extensive desktop and field pre-feasibility studies in order to identify sites in South Africa that would be suitable for possible future nuclear power generation. Subsequently, the Eskom Nuclear Site Investigation project, lead by a team of independent consultants, investigated sites along the South African coastline. Based on various social, economic and environmental criteria the following potential sites were identified:

- Bantamsklip (Western Cape – 10km south east of Pearly Beach)
- Brazil (Northern Cape – Kleinsee/Port Nolloth area)
- Duynefontein (Western Cape – adjacent to the existing Koeberg Power Station, Cape Town)
- Schulpfontein (Northern Cape – Hondeklipbaai/Kleinsee area)
- Thyspunt (Eastern Cape – West of Port Elizabeth near Cape St Francis)

The potential generating carrying capacity varies for each site. Consequently, the maximum generating capacity that is considered practical for each individual site will be evaluated as part of the Environmental Impact Assessment (EIA).

Eskom proposes to construct a nuclear power station of the Pressurised Water Reactor type technology. In many ways the structure of the nuclear power plant resembles that of a conventional thermal power plant. The difference between such plants is the manner in which the heat is produced. In a fossil plant, oil, gas or coal is fired in the boiler, which means that the chemical energy of the fuel is converted into heat. In a nuclear power plant, however, energy from the fission chain reaction is utilised. Cooling water for the nuclear power station will be utilised directly from the sea.

Although detailed design still needs to be completed it is estimated that the entire development will require in the order of 31ha, including all auxiliary infrastructure. The proposed nuclear power station will include the nuclear reactor, turbine complex, spent fuel, nuclear fuel storage facilities, waste handling facilities, intake and outfall basin and various auxiliary service infrastructure.

This report considers the Geotechnical Engineering aspects of the sites. The report is preliminary and based on a desk study of the information available at present. Further in-depth studies will be required before further evaluations can be completed.

The geotechnical characterization of the sites is an important design support activity. More detailed geotechnical studies are therefore intended to provide sufficient information to support:

- Siting of the nuclear footprint in integration with other disciplines (e.g. coastal engineering, seismic response determination, hydrogeology and ecology);
- Foundation design, excavation stability design, natural slope stability aspects, soil/groundwater interaction aspects and civil/geotechnics design interfaces as a minimum;
- Construction practicality definition.

2.2 Terms of Reference

The terms of reference for the specialist Geotechnical Assessment are to determine the parameters for the sites by means of site investigations and testing programmes for the following aspects:

- Free field seismic response and site specific response spectra
- Liquefaction potential
    - Evaluation of groundwater regime
    - Extent of soil layers
    - Average relative density
    - Undrained cyclic shear strength
    - Strain dependence of soil parameters
    - Past liquefaction history
    - Additional soil properties
- Stresses in the foundation materials
- Foundation stability
    - Bearing capacity
    - Overturning
    - Sliding
- Soil-structure interaction
    - Static analysis
    - Dynamic analysis
- Settlement and heave
- Earth pressure and stability of earth structures/buried structures
    - Natural slopes
    - Dykes and dams
    - Sea walls, breakwaters and revetments
    - Retaining walls
    - Embedded structures
    - Buried pipes, conduits and tunnels
- Nearest sources of suitable construction materials and their characteristics

It must be stated at the outset, that the aspects listed above are mainly determined by extensive field investigations and soil laboratory testing. This programme has not yet begun and therefore definitive results will not be available for some considerable time. Therefore, the comments made in this report are based on a desk study of the information currently available for the 5 sites. Detailed investigation may require that the interpretation be amended when the information becomes available.

3 BACKGROUND

3.1 Legislative Framework

The legislative framework that covers the licensing and construction of a nuclear power station includes the following:

- The National Nuclear Regulator Act (NNRA), Act No 47 of 1999
- The National Environmental Management Act (NEMA), Act No 107 of 1998
- The EIA regulations published in April 2006 promulgated in terms of NEMA

The NNRA and NEMA place emphasis on responsible geotechnical characterization of potential nuclear sites, notwithstanding the need to develop such sites in an environmentally acceptable manner.

3.2 Assumptions & Limitations

This report is a desk study based on the information available from Eskom for the various sites. Definitive engineering assessment will only be possible once the detailed site investigations have been done.

In addition, detailed layouts of the proposed development were not available for inclusion in this Scoping report. It is reasonable to assume that such data will not be available for some time and may only become available after a number of design iterations. This unavailability of data, although understandable, is a limitation on defining how the proposed development will be impacted by site specific geotechnical conditions and vice versa.

4 DESCRIPTION OF THE SITE AND SURROUNDING ENVIRONMENT

The locations of the proposed five sites are shown on Figure 4.1.

4.1 Thyspunt

4.1.1 Location and General Description

The Thyspunt site is located on the Eastern Cape coast approximately 15km due west of Cape St Francis and west of Oyster Bay and Tony's Bay. The site is fronted by a ragged beachfront, a 40m wide transition zone of swampy and mostly marshy vegetation caused by numerous fountains and freshwater seepage originating from the sand dune/bedrock contact, and a double bench dune system consisting of a lower terrace to a height of about 20mamsl and an upper terrace up to 50mamsl approximately 300m to the north. The dune system strikes East-North-East. The area is densely vegetated with typical Eastern Cape bush, shrubs and fynbos.

4.1.2 Geology

The geology of the site and environs is characterized by east-west trending steeply folded and faulted Cape Supergroup sediments and coastal embayments filled with Cretaceous sediments. Sandstones, siltstones and shales of the Table Mountain and Bokkeveld Groups underlie the area and have been folded and faulted due to the movement and thrusting associated with the breakup of Gondwanaland which is responsible for the formation of half-grabens (small "rift valleys") that subsequently filled with Cretaceous sediments eroded from the adjacent mountains. The westward movement of the Falkland Plate along the Agulhas-Falkland Fracture Zone has resulted in a drag-induced curvature to the eastern ends of the faults and folds that is particularly characteristic of the Eastern Cape.

Thyspunt is characterized by quartzitic sandstones that dip 50° south, due to the location on the southern limb of a major anticline; and NE striking gullies caused by selective erosion of the respective joint sets of the fold system and by abundant cross bedding. The weathering profile is due to the occurrence of softer bands of dark interbedded quartzite and carbonaceous shale, resulting in a ragged beachfront.

The sandstone is overlain by cobble and pebble beds of less than 2m thick, which is in turn, overlain by the stabilized sand dunes system with a thickness of between 5 and 20m.

The underlying rock terrace is therefore characterized by a succession of variably weathered ragged and jagged/saw-toothed basement gullies under the sand dunes. Excavation for the Nuclear terrace must therefore take these aspects into account in the geotechnical design of the site.

4.1.3 Geohydrology

Borehole testing on site prior to 1994 indicated relatively low permeability in the basement formations, but high dispersivity indicating possible fissures and preferential flow paths. Sea water intrusion is possible and could affect construction activities. The overlying dune system has a perched water table during the wet season and hence seepage along the contact with the basement formations can be expected.

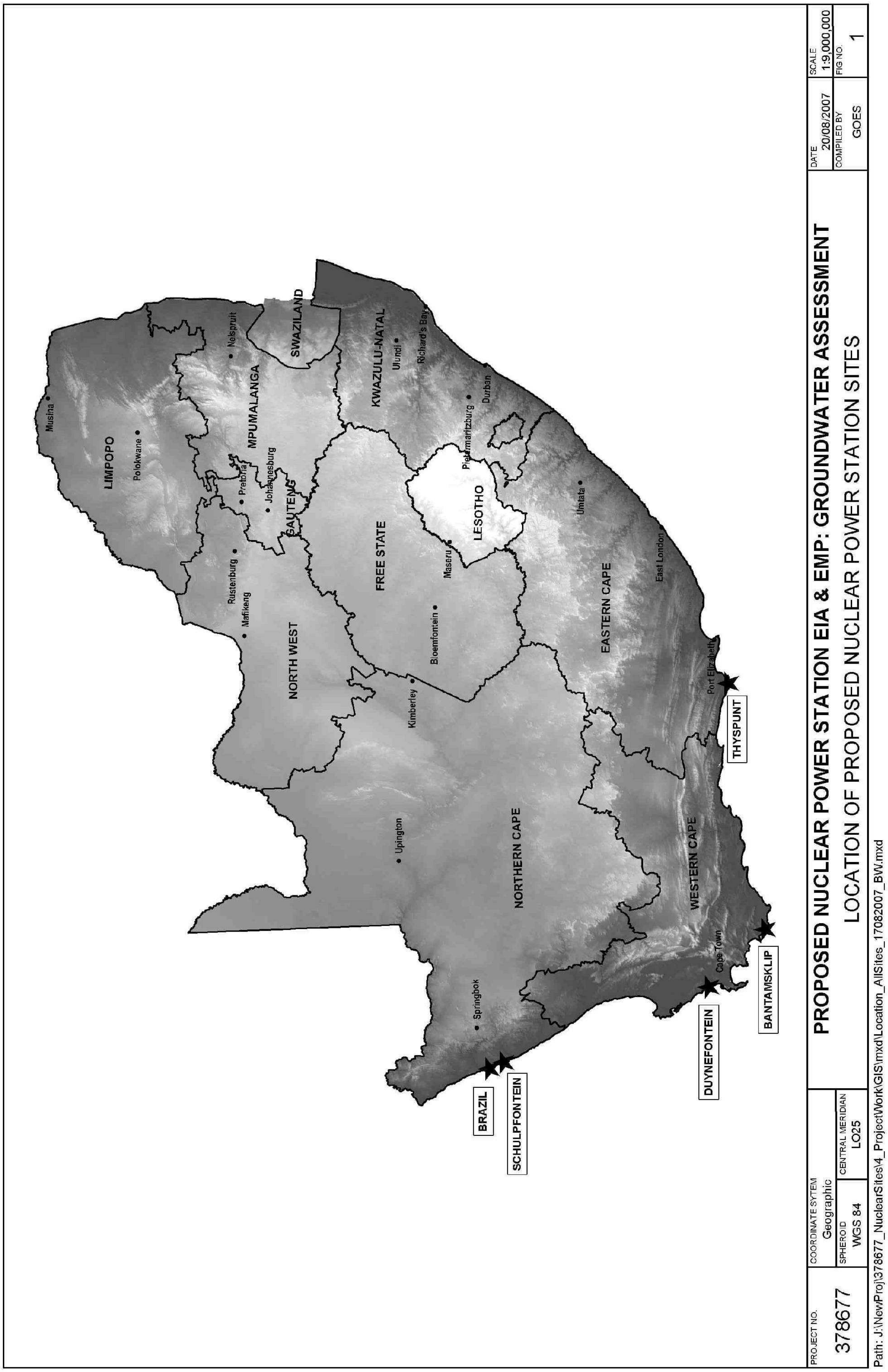

Figure 4.1: Location of the Proposed Nuclear Power Station Sites

4.1.4 Seismology

The seismology of the site (refer to the CGS geology and seismology study)

4.1.5 Geotechnical Interpretation

The Thyspunt site consists of sand dunes overlying steeply dipping and variably weathered quartzites and shales. Groundwater seepage is likely on the contact between the thick overburden and basement rock.

The sand dune terraces are semi-consolidated or unconsolidated and therefore will tend to form neutral equilibrium cut slopes at their natural angle of repose. The stability may be affected by seepage and occurrence of water at the interface and stable cut faces will require to be designed accordingly. The slope faces themselves will probably be susceptible to erosion and therefore vegetation re-establishment and/or other appropriate slope protection methods will be required. Structures built in the sands must take account of the variable consistency of the material and should be designed of normal Rankine earth pressure equivalent to a friction angle of 32° and cohesion of 0kPa. An additional constraint is the presence of cobbles and boulders which could make the use of sheet piles and certain type of piles difficult to install, if lateral support and alternative foundation types are necessary. The bearing capacity of the sand, in general will depend on the consistency of the various strata, and will range from 100 to 250kPa. Insitu compaction/densification of the sand layers should be possible, if required.

The underlying rock terrace consists of a succession of variably weathered saw-tooth-shaped ridges and gullies. The strength and stability of the rockmass is uncertain at this time but is likely to be variable due to the differential weathering, faulting and folding of the area. It is likely that particular attention will need to be paid to the foundation design to bridge potential weak zones in the formation. In areas where the overburden is thick and large load carrying capacity is required, piles or caisson-type foundations may be necessary.

The availability of construction materials on site is uncertain, but it is likely that they will have to be imported from commercial sources or quarries established in the vicinity and transported to site. Detailed quarry siting investigations may be required to ensure adequate quantity and quality of construction materials.

A comparative assessment of the sites is given in Table 4.1: Geotechnical Assessment of Potential Sites.

4.2 Bantamsklip

4.2.1 Location and General Description

The Bantamsklip site is located on the Southern Cape coast approximately 25km south east of Gansbaai and 45km west of Cape Agulhas. The quartizites that outcrop along the coastline are extensively jointed and faulted (striking NE) and result in a very ragged appearance and a number of parallel gullies. A beach terrace between 10 and 60m wide covers the area between the beach and the first dune. Minor seepages occur at the contact between the grassy flats and the bedrock with a few fountains in the faulted area on the northern portion of the site. A single dune with gentle easterly and westerly dipping slopes runs parallel to the coastline with a height of between 10 and 15mamsl. The area is vegetated by grass, bush and fynbos.

4.2.2 Geology

The site is underlain by Peninsula Formation quartzitic sandstone with minor shale bands and cross bedding. The consistency of the sandstone is often soft, sugary and brittle and can sometimes be broken with the fingers.

The quartzitic basement dips consistently 25 to 30° to the south east and forms a trend along at least 4km of the coastline that outcrops in the sea. The jointing is well developed and has resulted in the basement being eroded into a network of low-lying gullies which are also associated with numerous flexural slip faults that developed along the bedding planes. The fault zones consist of breccia, rock flour, mylonite, vein quartz and distorted shale bands and sporadic shearing. The flexural slip nature of the faults is clear and is confirmed by the abundance of slickensides. The basement topography is mostly below 4masml.

It is postulated that the major fault at Donkergat (to the northwest) could strike past the Site at a distance of approximately 1km to the northeast.

The overlying dunes are vegetated and semi-consolidated with alternating calcarenite and boulder beds.

4.2.3 Geohydrology

The permeability of the basement rock is categorized as low and therefore well yields are expected to be low. However, during construction, minor seawater intrusion can be expected. The overlying dune system acts as a 'perched' water table and seepage along the contact with the bedrock can be expected.

4.2.4 Seismology

The seismology of the site (refer to the CGS geology and seismology study)

4.2.5 Geotechnical Interpretation

The site consists of sand dunes overlying quartzites dipping relatively shallowly to the southeast.

The sand dune terraces are semi-consolidated or unconsolidated and therefore will tend towards their natural angle of repose but the stability may be affected by some seepage and occurrence of water at the interface and stable cut faces will require to be designed accordingly. The slope faces themselves will probably be susceptible to erosion and therefore vegetation re-establishment and/or other appropriate slope protection methods will be required. In addition, the presence of calcarenite and boulder beds in the sequence will improve the initial stability of the cut faces but continued weathering will probably make steep cut faces in this material unstable with time.

Structures built in the sands must take account of the variable consistency of the material and should be designed of normal Rankine earth pressure equivalent to a friction angle of 32° and cohesion of 0kPa. The calcarenite will exhibit some cohesion, but the reliance thereon will have to be carefully considered in the design phase. The presence of the cobbles and boulders could also make the use of sheet piles and certain type of piles difficult to install, if lateral support and alternative foundation types are necessary. The bearing capacity of the sand, in general will depend on the consistency of the various strata, and will range from 100 to 250kPa. Insitu compaction/densification of the sand layers should be possible, if required..

The underlying rock terrace consists of a succession of shallow (25°) variably weathered ridges and gullies. The strength and stability of the rockmass is uncertain at this time but is likely to be variable due to the differential weathering, faulting and folding of the area and the presence of fault zones containing breccia, rock flour etc. The rock classification is therefore likely to be poor, in general, with area of fair rock. The bearing capacity of the rock therefore should be down-graded to account for this variability. Particular attention will need to be paid to the foundation design in the potentially weak zones in the formation. In areas where the overburden is thick and large load carrying capacity is required, piles (see constraints above) or caisson-type foundations may be necessary.

The observation of slickensides on the rock joints is indicative of slip plane development. Therefore, it is likely that unstable wedges may form in rock excavations, where joints daylight or fault zones are present. Particular attention therefore must be given to excavations in this material, particularly where a considerable thickness of overburden exists. It will probably be necessary to stabilize unretained steep excavation faces with anchors and/or bolts both for temporary (construction) and permanent conditions.

The availability of construction materials on site is uncertain, but it is likely that they will have to be imported from commercial sources or quarries established in the vicinity and transported to site.

A comparative assessment of the sites is given in Table 4.1: Geotechnical Assessment of Potential Sites.

4.3 Duynefontein (existing Koeberg Power Station)

A considerable quantum of work has been focused on the existing Koeberg Power Station site. An extensive data base of geological and geotechnical information has been collected over the years. For the purposes of this report, only the salient features will be highlighted for overall comparison with the other sites. Sections of the Koeberg Site Safety Report (KSSR) 2006 have been included verbatim below (with some minor edits) for consistency and simplicity (shown in “ .. “)

4.3.1 Location and General Description

“The Koeberg site lies” approximately 30km north of Cape Town “within the coastal plain of the Western Cape Province, which is covered for the most part by Tertiary to Recent deposits.

Ancient dunes, stabilised by vegetation and Recent unconsolidated dunes, occupy large areas. This Sandveld rises gently towards the east and southeast to an average elevation of between 100 and 200 m some 20 km east of the Koeberg site. The south-eastern margin is demarcated by the Tierberg formation, whilst the Darling Range dissects the coastal plain in the north and the Blouberg hill forms a prominent feature some 10 km to the south of the Koeberg site” (KSSR 2006 ch10 p13).

4.3.2 Geology

"The surrounding area appears to be underlain almost entirely by folded rocks of the Malmesbury group. This statigraphic unit is typified by the Tygerberg formation, with greywackes, mudstones and intermittent shale bands being the principal rock types in the site area. These rocks are overlain by unconsolidated sands of Tertiary to Recent age. The time gap between the folded Malmesbury and the Tertiary exceeds 500 Ma. A member of a swarm of dolerite dykes occurs in the southern part of Duynefontein 34.

Boreholes, and a rock outcrop in the southern portion of Duynefontein, showed steeply dipping, somewhat sheared, slightly indurated greywackes interbedded with alternating mudstone layers beneath the site area. However, the steep dip of the formations was such that correlations could not be made between the relatively shallow, widely spaced holes, and their regional relationships could not be determined from the limited information available.

Orientated core samples indicated that the site area is underlain by isoclinally folded Malmesbury rocks, which conform in both lithology and structural deformation with the Tygerberg formation of the south-western Cape" (KSSR 2006 p29).

"In broad terms, the materials that were found to underlie the area consist of a sequence of variably calcareous and fossiliferous aeolian, estuarine and marine sands of considerable thickness deposited on a bedrock surface of interbedded greywackes, mudstones and shale bands. This bedrock surface, a wave-cut platform of Tertiary age, lies approximately 10,0 m below mean sea level at the coast.

Surface vegetation is generally minimal, but shells, discarded by strandlopers, are commonly seen. The underlying sands consist of an upper horizon which is mainly light grey to light brown, generally fine-grained with numerous interbedded medium- and coarse-grained lenses and layers, as well as calcrete which varies in its degree of development from a white dusty colouration to a well cemented bouldery layer, and variable but significant amounts of shell debris. This horizon is typically approximately 6,5 m thick.

The lower horizon, which can attain thicknesses in excess of 15 m, was originally divided into two separate sub-horizons but the only significant difference between them was in the colour variations. Both horizons consist of medium-dense to dense, fine to very fine sands with occasional shell fragments and they both contain thin bands of coarse sandy gravel. The upper portion was seen to be grey to dark grey due to the presence of organic matter and is estimated to be approximately 3,8 m thick, while the lower portion becomes greenish grey due to the absence of organic matter. The greenish colour is imparted by the mineral glauconite (a complex iron/potassium silicate). This horizon is the most homogeneous of the three layers and is very widespread along the west coast being found as far north as Hondeklipbaai and on the farms Somnaas and Schulpfontein, north of which it thins out and disappears.

The sand layers show a consistent trend in becoming finer-grained with increasing depth. No residual soil materials per se have been observed.

The term "greywackes" describes a group of rocks consisting of dark-coloured, poorly sorted clayey sandstones or fine grits. Bedrock materials encountered in the boreholes consist, in the unweathered state, of massive, fine- to medium- grained, quartzitic, occasionally cross-bedded, indurated, grey, extremely hard rock greywackes and fine-grained, even textured, moderately hard rock, grey or grey-green, bedded mudstones with subordinate micaceous laminated shale bands that are rare in occurrence but usually less than a metre in thickness.

“The underlying dark grey estuarine sand layer is more variable in thickness indicating that it has been eroded in places or was initially only very thinly deposited. This layer was observed to be very variable in material type, grading, colour and consistency over the power station area ” (KSSR 2006 ch10 p40-42).

4.3.3 Geohydrology

“Primary Aquifer: In the Koeberg site area the latest drilling indicated a profile consisting of 3 to 4,5 m of slightly calcareous sands at the top becoming organic rich with shell fragments below 7,5 m. Towards the base, the quartz grains are sub-rounded. This aquifer rests on weathered bedrock consisting of impermeable clay in places as indicated in BH 1. The thickness of the unconsolidated sediments is about 19,5 m with the water−level at about 7 m giving an aquifer thickness of ~12,5 m.

The catchment in which the Koeberg 900 MW PWR units 1 and 2 are located extends 12 km inland according to topographic maps and ground−water contours plotted by the Division of Geohydrology of the Department of Water Affairs. In this catchment the ground slope averaged 1 in 80, which is similar to the seaward ground−water gradient and the transmissivity has been calculated from recent pump test results at 40 m^2/day with an associated hydraulic conductivity of $4,6\times10^{-4}$ m/s^{-1} which compares very well with the overall hydraulic conductivity of 5×10^{-4} m/s^{-1} calculated by Dames and Moore.

There is a net movement of ground water towards the sea at an estimated rate of 2,6 m/day. At current rates of abstraction, however, the influence on Koeberg site is expected to be insignificant. The ground-water simulation report showed that seasonal rain variations will not significantly affect the ground-water flow or level in the area around the Koeberg site” (KSSR 2006 ch9 p3).

“Secondary Aquifer: The geology of the bedrock underlying the unconsolidated sediments in the vicinity of the Koeberg site has been described” elsewhere. **“**Bedrock at the site comprises an alternating succession of greywackes and mudstones of the Tygerberg formation, Malmesbury group. The rock is fractured and has secondary permeability. Recent drilling confirmed that the Malmesbury formation consists mainly of greywackes and siltstone with some mudstone layers. The bedrock dips to the west at 60° according to Greeff. Advanced weathering is generally confined to the upper 10 m of the rock mass. A 3,7 m thick layer of residual clayey silt was encountered at the top of the Malmesbury in one borehole.

The water levels measured in the borehole drilled into this aquifer confirmed the confined nature of this aquifer as the water struck at depth rose to about 7 m which is similar to that measured in the sedimentary boreholes. At the Koeberg 165 MW PBMR unit 3 site it was found that some hydraulic continuity exists between the primary and the secondary aquifers. However, the groundwater in the aquifer is probably stratified in age and quality. Transmissivity was calculated from the pump test conducted in this aquifer and a value of 30 m^2/day was obtained. This high hydraulic conductivity value of $3,4\times10^{-4}$ m/s^{-1} probably does not represent the overall aquifer as it was measured in a high permeable zone and the permeability of the Malmesbury aquifer as a whole, is likely to be far less” (KSSR 2006 ch9 p4).

4.3.4 Seismology

The seismology of the site (refer to the CGS geology and seismology study)

4.3.5 Geotechnical Interpretation

The site consists of sandy horizons up to 19m thick, overlying variably weathered Malmesbury Group rocks at depth. The area exhibits a fairly constant water table approximately 7m below surface.

Because of these factors, the choice of the exact position of the nuclear island on the site will be critical. Since the main structures will require to be founded on rock, the relative depth to the rock and the overburden must be accurately established with respect to the over burden (sand) thickness across the site.

The existing nuclear island was established in a similar situation and therefore extensive study of the construction techniques and problems encountered will be necessary during the investigation phase to establish the optimum geotechnical solutions.

The Duynefontein site is clearly more complex geotechnically than the other proposed sites. The presence of deep horizons of sand, coupled with the existence of a constant water table, makes the geotechnical design somewhat more challenging than it would appear on the other sites.

Slope stability below the water table is likely to be a constant problem and therefore the need for dewatering and/or support (lateral) for excavations will be required. Permanent support systems will be required to be designed for variable groundwater and loading (soil and external) conditions. In addition, deep excavations into rock will similarly be subject to groundwater intrusion.

The erosion potential of the surficial horizons is significant and hence surface stabilization measures will be necessary.

Liquefaction of the water bearing sands poses a medium risk as historical evidence of “soil-boils” and surface cracking under seismic conditions have been observed in the Cape Town area.

Bearing conditions in the Malmesbury Group rocks are expected to be medium to good. However, local characterization will be required during the investigation phase to establish the depth of weathering and its influence over the designated nuclear footprint. This investigation will define the necessity for alternative foundation solutions (compared to spreadfooting) for the range of loading conditions expected on the site. Founding conditions in the sands are expected to be of the order of 100 to 250kPa depending of the consistency and the settlement tolerance of the structures.

The site is in easy assess to commercial sources of construction materials, it is anticipated that these materials will therefore we transported to site from these sources. However, this will affect the traffic patterns and the consequential risk.

4.4 Brazil

4.4.1 Location and General Description

The Brazil site is located on the northwestern coast of Namaqualand approximately 20km south of Kleinsee and 55km north-northwest of Hondklipbaai. The site is situated on a broad coastal plain about 30km wide flanked by the Great escarpment and Bushmanland Plateau with a small embayment to the north. The coastline consists of rocky outcrop about 50 to 100m wide with a sandy undulating terrace towards the east that varies in elevation from 5 to 9mamsl. The coastal dune ridge is unconsolidated and stabilized by vegetation while semi-consolidated sand occurs further inland.

The area is characterized by diamondiferous marine and fluvial gravels, boulders and cobble beds that have accumulated in the erosion gullies of the basement rocks. Diamond mining is on-going in the area. Where mining has stopped, large areas have been remediated. Open exploration trenches are common in the area.

4.4.2 Geology

The regional basement rocks for both the Brazil and Schulpfontein sites consist of granites, gneisses and quartzites of the Namaqualand Metamorphic Complex overlain by quartzitic sandstones and schists of the Stinkfontein Sequence. The local geology consists of fine to medium grained horneblend-bearing Brazil granite with amphibolite zones/dykes. The amphibolite zones are more prone to weathering and this has caused the deeper weathering along the central north-south axis of the site.

The granite is overlain by thin deposits of boulders, cobbles and calcrete which in turn are overlain by semi-consolidated coastal sand dunes.

4.4.3 Geohydrology

Little groundwater is present on site. Seawater was apparently intercepted in some boreholes during the investigation carried out prior to 1994.

4.4.4 Seismology

The seismology of the site (refer to the CGS geology and seismology study)

4.4.5 Geotechnical Interpretation

The site consists of sand including marine and fluvial gravel, boulder and cobble beds overlying granite bedrock.

The sand/boulders/cobbles have accumulated in the undulating erosion gullies of the bedrock and are likely to be of the order of 2 to 4m thick and calcretised over extensive areas. Due to the relative thinness of the overburden, stability of this material is unlikely to cause problems. Similarly, it is likely that the material can be used to form construction terraces with a minimum of imported basecourse material as a wearing surface. Bearing capacity with the sand horizons are likely to be in the range 150-300kPa depending of the consistency and the presence of calcrete and boulders.

The underlying granite bedrock will form an excellent founding layer. However, some caution must be exercised in the design of foundation due to the presence of amphibolite zones/dykes which are prone to weathering and may exhibit variable founding conditions in places, particularly where highly loaded areas are envisaged. Due to the apparent lack of structure in the granites, excavations are likely to be stable to 5m. However, local mapping and assessment must be carried out to ensure that this is achievable.

The availability of construction materials on site remains uncertain. Goraap se Kop in the vicinity has previously been identified as a source of aggregate and the Buffels River as a source of sand. In addition, it may be possible to establish a quarry on site, but this will depend on extensive site investigation and assessment of the near surface quality of the granite. Alternatively, commercial sources or quarries established in the vicinity and transported to site will have to be used.

A comparative assessment of the sites is given in Table 4.1: Geotechnical Assessment of Potential Sites.

4.5 Schulpfontein

4.5.1 Location and General Description

The Schulpfontein site is situated along the same section of coastline as the Brazil site but further south. It is located about 50km south of Kleinsee and 30km NNW of Hondeklipbaai. The site is situated on a broad coastal plain about 30km wide flank by the Great escarpment and Bushmanland Plateau between two small embayments. The coastline consists of rocky outcrop about 50 to 100m wide with a sandy undulating terrace towards the east that rises steadily to an elevation of about 20mamsl. The thin overlying coastal dunes are semi-consolidated and stabilized by vegetation. Outcrops of calcrete, calcretised sand and basement rocks occur in places. Active dune fields occur about 7km north along the coast and 5km inland from the site.

The area is characterized by diamondiferous marine and fluvial gravels, boulders and cobble beds that have accumulated in the erosion gullies of the basement rocks. Diamond mining is on-going in the area. Where mining has stopped, large areas have been remediated. Open exploration trenches are common in the area.

4.5.2 Geology

The regional basement rocks for both the Brazil and Schulpfontein sites consist of granites, gneisses and quartzities of the Namaqualand Metamorphic Complex overlain by quartizitic sandstones and schists of the Stinkfontein Sequence. The local geology consists of Nababeep gneiss with a consistent and uniform structure. Some minor volcanic intrusions occur in the vicinity. The gneiss is overlain by a calcrete bank which sometimes occurs with an underlying clayey sand layer that is potentially dispersive. This sequence is overlain by semi-consolidated medium to fine grained sand on average 2m thick over the site. No faults have been detected in the vicinity of the site.

4.5.3 Geohydrology

Little groundwater is present on site. Seawater was intercepted (at undefined depths – ref NSIP Report) in some boreholes during the investigation carried out prior to 1994.

4.5.4 Seismology

The seismology of the site (refer to the CGS geology and seismology study)

4.5.5 Geotechnical Interpretation

The site consists of sand including marine and fluvial gravel, boulder and cobble beds overlying gneiss and quartzite bedrock.

The sand/boulders/cobbles have accumulated in the undulating erosion gullies of the bedrock and a likely to be of the order of 2 to 6m thick and calcretised over extensive areas. Due to the relative thinness of the overburden, stability of this material is unlikely to cause problems. However, the presence of a clayey sand horizon under the calcrete that is more susceptible to erosion (and is possible dispersive), will result in undercutting and potential instability of the more competent calcrete bands. However, it is likely that the calcrete and sand horizons can be used to form construction terraces with a minimum of imported basecourse material as a wearing surface. Bearing capacity with the sand horizons are likely to be in the range 150-300kPa depending of the consistency and the presence of calcrete and boulders.

The underlying gneiss and quartzite bedrock will form an excellent founding layer. However, some caution must be exercised in the design of foundation in places due to the sugary weathered texture of both rock types. Excavations in fresh rock are likely to be stable to 5m. However, local mapping and assessment must be carried out to ensure that this is achievable and that the rock structure is not detrimental.

The availability of construction materials on site remains uncertain. Goraap se Kop in the vicinity has previously been identified as a source of aggregate and the Buffels River as a source of sand. In addition, it may be possible to establish a quarry on site, but this will depend on extensive site investigation and assessment of the near surface quality of the granite. Alternatively, commercial sources or quarries established in the vicinity and transported to site will have to be used.

A comparative assessment of the sites is given in Table 4.1: Geotechnical Assessment of Potential Sites.

Table 4.1: Geotechnical Assessment of Potential Nuclear Sites.

Aspect	Nuclear Facility				
	Thyspunt	**Bantamsklip**	**Duynefontein**	**Brazil**	**Schulpfontein**
Seismic Response	low	low	Low to medium	Very low	Very low
Liquefaction Potential	Low to medium	Low to medium	medium	low	Low
o Groundwater regime	Seepage/fountains on bedrock contact	Seepage/fountains on bedrock contact	Extensive: groundwater abstract possible	Little groundwater	Little groundwater
o Extent of Soil layers	Dune sand 5 to 20m thick; cobbles and boulders up to 2m thick	Dune sand 4 to 12m thick. Calcarenite and boulder beds	Unconsolidates sediments 19.5m, water table at 7m. Layer 1 6.56m (±2.7m); Layer 2 3.79m (±1.9m); Layer 3 8.47m (±2.3m)	Sand and calcretes: 2 to 4m thick	Sand, calcrete and Clayey silt sand, 2 to 6m thick
o Average relative density	Sand 1650kN/m^3	Sand 1650kN/m^3	All layers 70% (±20%); 1700kN/m^3	Sand 1600kN/m^3	Sand 1600kN/m^3
o Undrained cyclical shear strength	No information. Likley phi = 32°, c = 0kPa in sand; c=20kPa in calcrete	No information. Likley phi = 32°, c = 0kPa in sand; c=20-50kPa in calcrete	Phi (peak/resid) 35-38°, c = 30kPa	No information. Likley phi = 32°, c = 0kPa in sand; c=20-30kPa in calcrete	No information. Likley phi = 32°, c = 0kPa in sand; c=20-40-kPa in calcrete
o Strain dependence of soil parameters	No information. About 25MPa	No information. About 30MPa	Young's Modulus (ave) = 29MPa	No information. About 40MPa	No information. About 40MPa
o Past liquefaction history	No information. Likely to be low	No information. Likely to be low	Sand boils and surface cracking reported in Cape Town area	No information. Likely to be low	No information. Likely to be low
o Addtitional soil properties	Cobbles and boulders	Calcarenite and boulder beds	Residual clayey silt overlying fractured Malmesbury shale	Calcrete	Calcretise sand and clayey silty sand horizons (possibly dispersive)
Stresses in foundation materials	No information. Rankine for phi = 32°	No informati on. Rankine for phi = 32°	Rankine for phi = 35°	No information. Rankine for phi = 32°	No information . Rankine for phi = 32°
Foundation Stability	Good - variable	Good to Poor	Medium	Excellent	Excellent
o Bearing capacity	Sand 100 to 250kPa depending on consistency. Rock: up to 5MPa in bedrock, depending on weathering. Piling for deep foundations (gullies)	Sand 100 to 250kPa depending on consistency. Rock: up to 5MPa in bedrock, depending on weathering. Piling for deep foundations (gullies)	Sand 100 to 250kPa depending on consistency. Rock: up to 5MPa in bedrock, depending on weathering. Piling for deep foundations (gullies)	Sand 150 to 300Pa depending on consistency. Rock: up to 5MPa in bedrock, depending on weathering. Spreadfootings only reqd	Sand 150 to 250kPa depending on consistency. Rock: up to 5MPa in bedrock, depending on weathering. Spreadfootings only reqd
o Overturning	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters
o Sliding	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters
Soil-structure interaction					
o Static Analysis	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters
o Dynamic Analysis	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters
Settlement and heave	Bearing capacity values will result in 25mm settlement. Heave	Bearing capacity values will result in 25mm settlement. Heave	Bearing capacity values will result in 25mm settlement. Heave very low	Bearing capacity values will result in 25mm settlement. Heave	Bearing capacity values will result in 25mm settlement.

Aspect	Nuclear Facility				
	Thyspunt	**Bantamsklip**	**Duynefontein**	**Brazil**	**Schulpfontein**
	unlikely/very low	unlikely/very low		unlikely/very low	Heave unlikely/very low
Earth pressure and stability of earth structures/buried structures	Conventional design criteria for surface structures; potentially problematic subsurface/rock conditions due to weathering, joints, fractures and faults	Conventional design criteria for surface structures; potentially problematic subsurface/rock conditions due to weathering, joints, fractures and faults	Conventional design criteria for surface structures; potentially problematic subsurface/rock conditions due to weathering, joints, fractures and faults	Conventional design criteria for surface structures; good subsurface/rock conditions	Conventional design criteria for surface structures; good subsurface/rock conditions
o Natural slopes	1:2.5 for natural sand slopes. Severe erosion potential. Instability at contact. Steep wedge instability (50°) in rock exposures on the northern side of excavations due to bedding, joints and faults.	1:2.5 for natural sand slopes. Severe erosion potential. Instability at contact. Shallow wedge instability (<=25°) in rock exposures on the western sides of excavations, due to bedding joints and faults.	1:2.5 for natural sand slopes. Severe erosion potential. Instability at contact. Steep wedge instability (<45°) in rock weathered and fractures exposures.	1:2.5 for natural sand slopes. Some erosion potential. Minor instability at contact. Vertical rock exposures probably stable to 5m.	1:2.5 for natural sand slopes. Some erosion potential. Minor instability at contact. Vertical rock exposures probably stable to 5m.
o Dykes and dams	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials
o Seawalls, breakwater and revetments	Stable in offshore rock outcrop	Stable in offshore rock outcrop	Stable in offshore rock outcrop	Stable in offshore rock outcrop	Stable in offshore rock outcrop
o Retaining walls	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters	Depends on situation, loading and material parameters
o Embedded structures	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials
o Buried pipes, conduits and tunnels	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials	Depends on location, elevation, insitu and construction materials
Nearest sources of suitable construction materials	Commercial/transport	Commercial/transport	Local	Local/transport	Local/transport
o Aggregate	Commercial quarries, establish local crusher off site	Commercial quarries, establish local crusher off site	Commercial quarries	Commercial quarries or crusher at Goraap se Kop	Commercial quarries or crusher at Goraap se Kop
o Sand	Commercial sources, local	Commercial sources, local	Commercial sources	Commercial sources or Buffels River	Commercial sources or Buffels River
o Cement	PPC transport from Port Elizabeth	PPC transport from Cape Town	PPC local supply	PPC transport from DeHoek	PPC transport from DeHoek
o Basecourse/subbase	Local source to be identified	Local source to be identified	Commercial sources	Local source to be identified	Local source to be identified

5 IMPACTS AND MITIGATION MEASURES

5.1 Project Impacts and Mitigation Measures

5.1.1 Project Impacts on the Environment

Construction projects of this nature, from a geotechnical engineering perspective, have a number of generic impacts on the environment which can be mitigated to a large degree by the sensitivity in design. This can then be effectively incorporated into an Environmental Management Plan (EMP) for practical control during construction. These aspects include:

- Excavation on site: dust generation and slope stability in particular generically need to be carried out under the guidance of an EMP.
- Spoil on site and off site: the integrity of spoil heaps and their susceptibility to erosion as well as the siting of spoil heaps are important issues.
- Quarries off site: quarry optimisation to minimize disturbed area and quarry closure are key factors requiring careful planning and geotechnical design to inform the EMP
- Roads and access ways: the excavation, fill and importation of materials for road and access way construction generically introduce dust management needs, responsible spoiling of material and road slope stability issues as well as the need for an engineered response to erosion control.
- Pipelines and supply routes: excavation, fill and materials access all contribute to the disturbed footprint that requires optimisation in design
- Erosion of manmade surfaces (spoil dumps, cut slopes, embankment slopes)
- Slope failures, depending on the spatial nature of failure can have significant impacts in both extent (physical size of displaced material in failure) or when the receiving environment is sensitive (e.g. failure of a fill slope into a preserved wetland).
- Water table drawdown for temporary and permanent works purposes can impact on surface water features (although most probably in the short term) like wetlands that are recharged by groundwater.
- Potential water table disruption from permanent works: permanent structures can impede natural groundwater flow and flow direction, having a negative impact on surface water features recharged by groundwater.
- Geotechnical Construction equipment: Excavators and other plant, Piling rigs, Drilling rigs: responsible use, management and maintenance of such equipment is a mandatory requirement in all EMPs to minimise impact on the environment (e.g. diesel spillage/storage management)

5.1.2 Mitigation Measures

Since the aspects defined above are all technical by nature, design options such as limiting of slope angles, definition of road ways to minimise damage, judicious choice of plant and equipment and an extensive rehabilitation plan (defined at the outset) will mitigate the impacts on the environment. Sensitivity in design therefore needs to inform the EMP so that practical control can be affected during construction and penalties introduced for irresponsible construction behaviour.

6 SITE SENSITIVITY ANALYSIS

6.1 Criteria for Site Sensitivity Analysis

In terms of geotechnical engineering considerations these criteria are listed below:

- Seismic response;
- Liquefaction potential;
- Foundation stability;
- Settlement and heave;
- Earth pressure and stability of earth structures/buried structures;
- Construction material sources.

6.2 Site Sensitivity

Based on the above criteria, and the preliminary assessment of the significance of these criteria at each of the sites, the following can be highlighted with respect to site sensitivity (note that the sites appear from highest to lowest sensitivity in the sub-bullets):

- Seismic response aspects were initially assessed as follows;
  - Dynefontein (low to medium)
  - Thyspunt (low);
  - Bantamsklip (low);
  - Brazil (very low);
  - Schulpfontein (very low).
- Liquefaction potential;
  - Dynefontein (medium)
  - Thyspunt (low to medium);
  - Bantamsklip (low to medium);
  - Brazil (low);
  - Schulpfontein (low).
- Foundation stability;
  - Bantamsklip (good to poor);
  - Dynefontein (medium)
  - Thyspunt (good);
  - Brazil (excellent);
  - Schulpfontein (excellent).
- Settlement and heave (note all sites are expected to exhibit similar settlement characteristics):

  - Dynefontein (heave very low)
  - Bantamsklip (heave unlikely/very low);
  - Thyspunt (heave unlikely/very low);
  - Brazil (heave unlikely/very low);
  - Schulpfontein (heave unlikely/very low).
- Earth pressure and stability of earth structures/buried structures;
  - Bantamsklip (potentially problematic subsurface conditions);
  - Dynefontein (potentially problematic subsurface conditions)
  - Thyspunt (potentially problematic subsurface conditions);
  - Brazil (good subsurface conditions);
  - Schulpfontein (good subsurface conditions).
- Construction material sources:
  - Bantamsklip (commercially obtainable only – high transport costs);
  - Thyspunt (commercially obtainable only – high transport costs);
  - Brazil (locally obtainable with some transport costs);
  - Schulpfontein (locally obtainable with some transport costs).
  - Dynefontein (Locally obtainable)

Based on the above preliminary sensitivity analysis, the overall site sensitivity analysis with respect to geotechnical engineering aspects is (ranked from highest to lowest sensitivity):

- Bantamsklip/Dynefontein;
- Thyspunt;
- Brazil/Schulpfontein.

7 CONCLUSIONS

This report has focussed on the geotechnical engineering aspects of the 5 proposed nuclear power station sites on the Eastern Cape, Southern Cape and Western Cape coastal areas. Since a detailed site investigation of the proposed sites has not yet commenced, the comments and assessments made are based on information and documentation currently available. This will be updated once the detailed information becomes available.

The character of the sites is fundamentally different:

- The Thyspunt and Bantamsklip sites have some similarities with regard to the sand dune overburden overlying saw-toothed erosion gullies in the bedrock. These sites are categorised as good to poor but variable from a geotechnical perspective. Besides down graded bearing capacity due to the variability, erosion and slope stability could be problematic and must be engineered carefully.

- The Duynefontein site (Koeberg) is characterised by thick horizons of variably consolidated sands up to 19m thick overlying variably weathered Malmesbury Group shales, mudstones and greywackes. The groundwater is at about 7m below surface and hence will have a considerable influence on geotechnical structures and require dewatering and permanent protection measures. Also, the liquefaction potential is significantly higher on this site compared to the other proposed sites. Historically, soil boils and surface cracking have been recorded under seismic conditions in the Cape Town areas.

- The Brazil and Schulpfontein sites are characteristically similar albeit that they are located on different base rock types. The overburden sand, calcrete with boulders and cobbles are in general 2 to 6m thick and should not cause geotechnical problems. The underlying bedrock of granite and gneiss/quartzite, respectively, are competent and relatively uniform thus leading to the conclusion of excellent founding conditions. Some caution must be exercised with regard to preferential weathering of amphibolite (granite) and sugary gneiss/quartzite on the sites. Groundwater is unlikely to pose a problem and erosion is likely minor, but must be controlled by judicious design.

8 REFERENCES

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