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APPENDICES

ATTACHMENT A
MAPS - WESTERN PRECINCT

Map 1: Regional Geology

Map 2: Regional Hydrogeology

Map 3: Borehole Drilling Depths

Map 4: Depth to Water Level

Map 5: Water Quality (EC)

Map 6: Registered Water Use

ATTACHMENT B
Document Limitations

1.0 BRIEF OVERVIEW OF THE PROPOSED EXPLORATION APPLICATION PROJECT

This report presents the results of a desktop study addressing the groundwater aspects of the EMP for the proposed shale gas exploration activities for the Western Precinct Area. The study area is shown in **Error! Reference source not found.**.

Groundwater resources are widely used to support agriculture (stock and game watering) and rural communities. A number of larger towns in the Karoo (with populations > 2500) are also either solely or, conjunctively with surface sources, dependent on groundwater for their domestic water supplies.

Proposed gas exploration activities will include: geophysical data acquisition and studies; and drilling exploration wells with possible hydraulic fracturing for gas stimulation. The exploration wells are anticipated to be drilled to depths of between 1 500m below surface and 4 500m below surface to intersect potentially gas bearing shale horizons.

2.0 OBJECTIVES

This technical report provides a regional overview of the hydrogeological setting of the WesternPrecinct. The document aims to set the context within which later detailed groundwater investigations will be undertaken as part of the subsequent EIA study.

A preliminary impact assessment is included at the request of the regulators. This work has been done before the gas exploration sites have been chosen and therefore can only be based on a generic case. It is not the objective of this EMP report to provide a detailed assessment of site specific conditions, since the gas exploration drilling sites have not yet been selected.

Sites for the drilling of gas exploration wells will only be selected once the exploration right applied has been approved and after a rigorous site selection process. The later will be based on field conditions rather than theory. This site selection process will include a detailed site assessment of the prevailing groundwater situation, (occurrence, aquifer thickness, rock type, depth to water table, flow direction, groundwater quality), a technical assessment and the identification of appropriate site specific mitigation measures.

3.0 METHODOLOGY

A regional desktop study of the hydrogeology was conducted of the general Karoo Basin and the Western Precinct to provide an overview for the EMP and project planning.

The high level overview of the hydrogeology of the Karoo Aquifers is sourced and largely quoted/abstracted from published specialist studies by the Department of Water Affairs (DWA), Water Research Commission (WRC) and Institute for Groundwater Studies; conducted either at national or regional scale between 1991 and 2002.

The published specialist studies/reports sourced include:

- J Kirchner, GJ van Tonder, and E Lukas (1991) "Exploitation potential of Karoo Aquifers", Institute for Groundwater Studies, WRC Report No 170/1/91.
- JR Vegter, (1995) "An Explanation of a Set of National Groundwater Maps", Water Research Commission, Report No. TT 74/95.
- AC Woodford and L Chevallier (2002) "Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs", Water Research Commission, Report No. TT179/02
- The regional geology for the Eastern, Central and Western Precincts was compiled from published 1:250,000 scale maps by the Council of Geoscience and use of the simplified geology of South Africa by DWA. The regional hydrogeological knowledge and understanding of Karoo aquifers was sourced from published hydrogeological 1:500,000 scale maps (1996 - 2003) and national groundwater data by DWA.

A full list of references is given in the references at the end of this document.

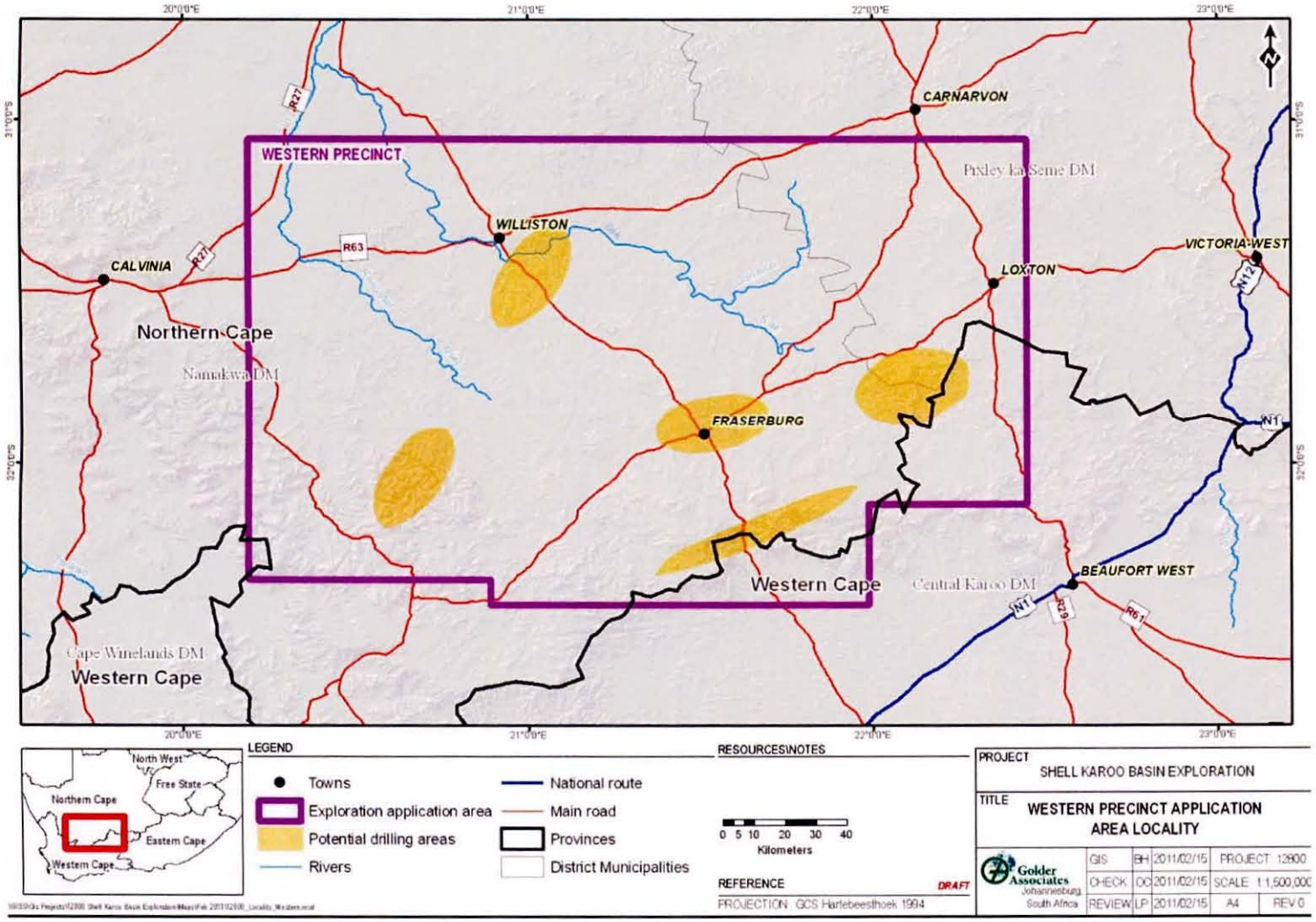

Figure 1: Exploration Application Area

Groundwater data were obtained from the following DWA sources:

- National Groundwater Database (NGDB), dated October 2008,
- Water Quality Management System (WQMS), dated October 2008, and
- Water Authorization and Registration Management System (WARMS), dated June 2010.

The data from these data bases have been used to compile the following 6 maps for the Western Precinct:

- Regional Geology
- Regional Hydrogeology, depicting groundwater occurrence and borehole yield
- Borehole Drilling Depths
- Depth to Water Level
- Water Quality (EC)
- Registered Water Use

These maps are presented in this report as Attachment A. They indicate the status of the groundwater resources of the precinct.

3.1 Field Verification

A field verification of the area studied was undertaken to gain a first-hand overview of the geological and hydrogeological setting, to support the desk study information and to help develop subsequent technical assessment.

The main objectives of the fieldwork were to gain a general overview and understanding of the landscapes and hydrogeological features present in the precinct, together with roadside and more distant rock exposures, in order to:

- Clarify the distribution, understanding and meaning of the important aspects of the Karoo described in the publications, which might have a significant effect on the hydrogeology, groundwater occurrence and usage, and potential impacts of the proposed gas exploration;
- Confirm the general geological and hydrogeological settings of groundwater abstraction boreholes.

4.0 BASELINE DESCRIPTION OF THE STUDY AREA

4.1 Overview of the Karoo Basin

4.1.1 Physiography

The Main Karoo Basin covers the greater part of the central region of South Africa (Figure 2). Surface altitudes range from 800 to 3650 m above mean sea level. Altitudes are highest in the east decreasing gradually as the surface slopes to the west. The generally flat to undulating topography is broken by the up-warped plateau edges and the escarpment, most prominent in the Drakensberg region.

A typical feature of the landscape of the Western Karoo Basin is the flat-topped hills, which are often capped by more resistant dolerite sills or sandstone beds, rising above the featureless and flat to undulating plains. Outcrops are rare between hills due to the surface cover of calcrete, windblown sand, alluvium, collovium and soil.

Dolerite sill and ring-complexes are often prominent features of the Karoo landscape. These structures are easily recognized on satellite images, where they often display a sub-circular saucer-like shape, the rims of which are commonly exposed as topographic highs forming ring-like outcrops.

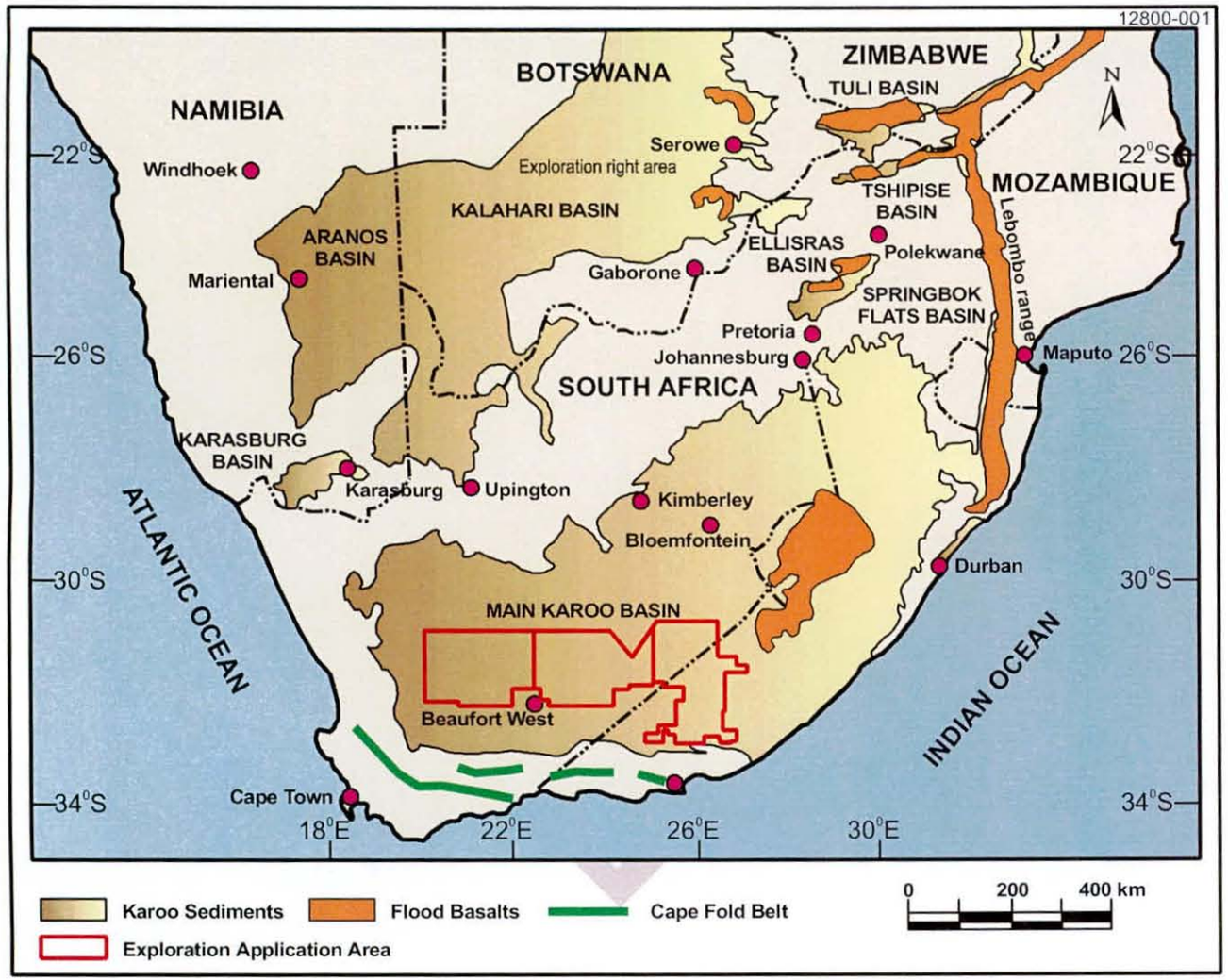

Figure 2: Main Karoo Basin of Southern Africa

4.1.2 Climate and Rainfall

The climate of the South Western Karoo Basin ranges from arid (MAP<200mm) to semi-arid (MAP<500mm) and is classified as a summer rainfall region. Mean annual rainfall (MAP) decreases from east (500mm) to the west (<200mm). The major drainage feature is the Orange River and its perennial tributaries. The rivers in the Western Karoo Basin are seasonal, flowing only for short periods of time following heavy rainfall (Woodford 2002).

During the summer months, moisture-laden air flows from the Indian Ocean giving rise to thunderstorm activity and rain. Evaporation is highest during the summer months, further depleting the available moisture in arid areas. The major source of groundwater recharge is rainfall.

Rainfall patterns in arid to semi-arid regions are irregular in terms of depths (mm), intensities (mm/hr) and footprints (km^2). During wetter seasons the footprint is larger and sporadically generates local flush flooding and depression storage (Van Wyk 2010). Indirect recharge in these cases occurs as point-source recharge zones in an otherwise low potential diffuse recharge environment. Intermittent or episodic recharge events in semi-arid regions correlate with extraordinary rainfall events and instigate medium-term aquifer replenishment. Recharge in this climate is not necessarily an annual event (Vegter 1995).

A few mean annual groundwater recharge estimates for Karoo aquifers in semi-arid regions are listed by Vegter (1995) and range between 16 to 22 mm. In the arid region mean annual recharge varies between 5 to 15 mm.

4.1.3 Geology

The Main Karoo Basin has been controlled and shaped by four major geodynamic events (Woodford 2002):

- Deposition of the Karoo sediments and the uplift of the Cape Fold Belt,
- Intrusion of Karoo basalt and dolerite,
- Intrusion of Kimberlite and localised mantle up-welling,
- Modern geomorphology, deposition of recent sediments, uplift, cessation of regional tectonics.

The geology of the Main Karoo Basin is summarized from Woodford (2002). The present day Main Karoo Basin is in-filled with sedimentary strata which are capped by a 1.4 km thick unit of basaltic lava. Major lithostratigraphic units of the Karoo Supergroup are shown in Figure 3 and Figure 4.

The lithostratigraphic units of the Karoo Supergroup outcrop concentrically around the Main Karoo Basin. Lateral facies changes, particularly in the lower half of the succession, have given rise to inter-tonguing of lithologies in various parts of the basin. No major regional unconformities are known to exist within the basin, with the possible exception of one at the base of the Molteno Formation (Woodford 2002).

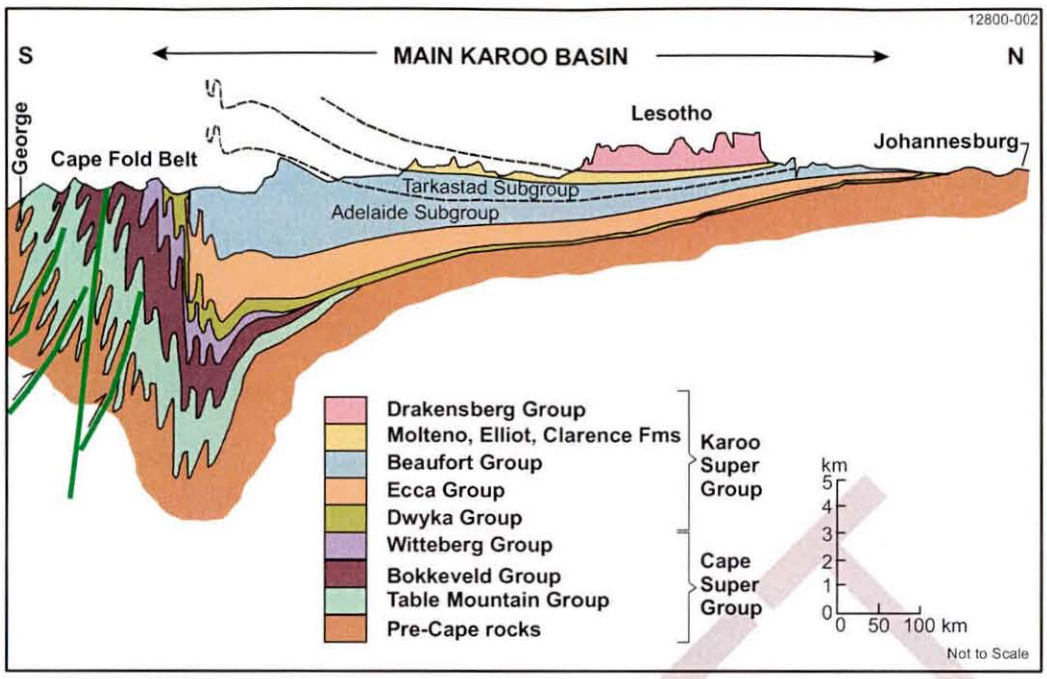

Figure 3: Cross Section of the Main Karoo Basin (reproduced from Woodford 2002)

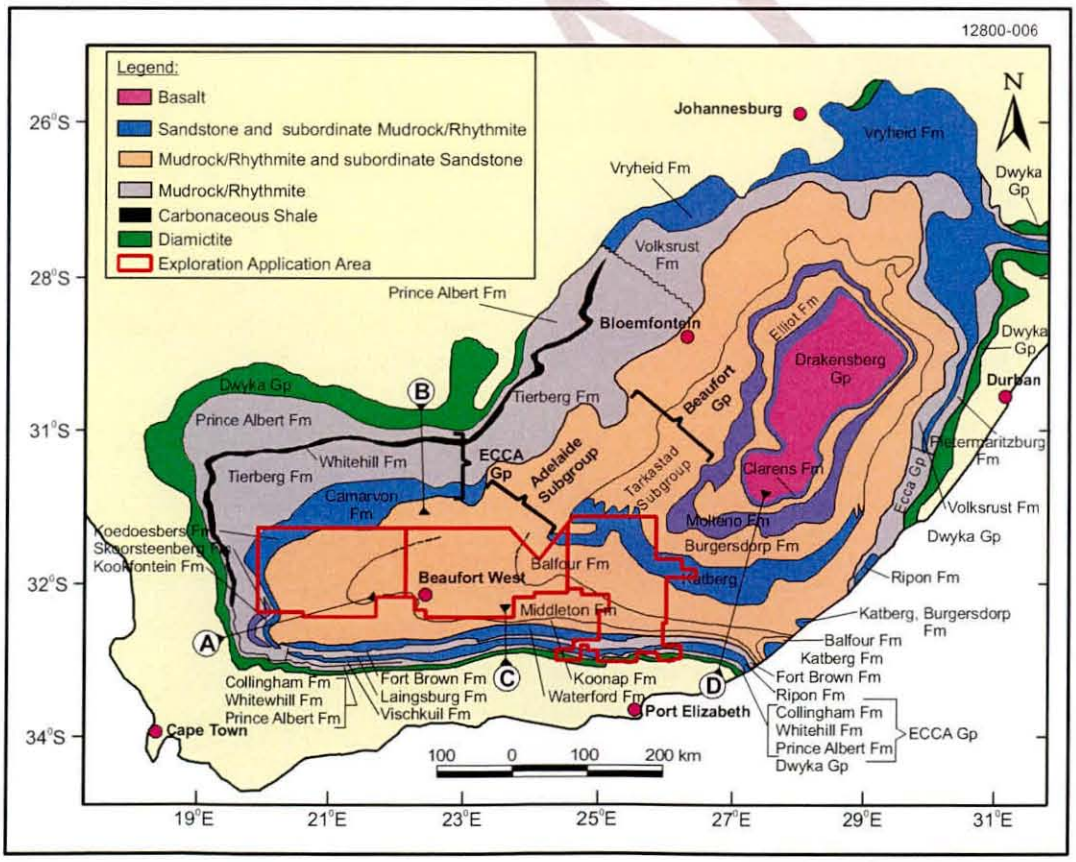

Figure 4: Schematic Areal Distributions of Lithostratigraphic Units in the Main Karoo Basin (reproduced from Woodford 2002)

The various lithologies making up the stratigraphic units of the Karoo sequence, commencing at the base, are briefly described below:

4.1.3.1 Dwyka Group

The Dwyka Group sediments were deposited by glacial processes and consist mainly of diamictite (tillite) which is generally massive with little jointing. Subordinate rock types are conglomerate, sandstone, rhythmite and mudstone. The Dwyka diamictite consists of angular to rounded clasts of basement rock embedded in a clay and silt matrix. The Dwyka Group attains a maximum thickness of 800 metres in the southern parts of the basin. The water body was marine as shown by the presence of marine fossils in mudstone units.

4.1.3.2 Ecca Group

The Ecca Group sediments comprise a total of 16 formations, reflecting the lateral facies changes that characterise this succession. The formations present in the southern and western basins are briefly discussed below.

- The Price Albert Formation (Lower Ecca) is confined to the south-western half of the Karoo Basin, with a variable thickness of 40 to 150 metres. The southern facies is characterised by predominant dark-grey, pyrite bearing, splintery shale and siltstone.
- The Whitehill Formation (Lower Ecca) contains mudrock which weathers white on surface, making it a very useful marker unit. The dominant facies is black carbonaceous, pyrite-bearing shale. The shale is very thinly laminated and contains up to 14 per cent carbonaceous material. The thickness varies from 10 to 80 metres and contains the fossilized reptile Mesosaurus. This Formation is reported to be characterised by a high groundwater salinity.
- The Collingham Formation (Upper Ecca) comprises interbedded thin (average of 5 cm) continuous beds of hard dark-grey siliceous mudrock and very thin beds (average of 2 cm) of softer yellowish tuff (K-bentonite). The formation is generally between 30 and 70 metres thick with minor sandstone units occurring in the upper half of the formation.
- The Vischkuil Formation (Upper Ecca) varies in thickness between 200 and 400 metres. It consists essentially of dark shale, alternating with subordinate fine-grained sandstone, siltstone and minor tuff layers. The presence of minor tuff beds in the shale indicates continued volcanic activity. An upward increase in thickness and abundance of sandstone exists.
- Laingsburg Formation comprises four sandstone-rich units separated by shale units and is approximately 400 metres thick. The thick massive sandstone units (up to 30 metres thick, with individual beds up to 4 metres thick) are fine-grained to medium-grained with sharp upper and lower contacts. They grade upward into laminated siltstone and shale, which commonly contain coalified plant fragments.
- The Ripon Formation is generally 600 - 700 metres thick. It consists of poorly sorted, fine to very-fine grained feldspathic sandstone alternating with dark grey clastic rhythmite and mudrock.
- The Fort Brown Formation consists of rhythmite and mudrock with minor sandstone and displays an overall coarsening-upward sequence. The average thickness is about 1000 metres, this can vary from about 500 to 1,500 metres.
- The Water Ford Formation of the South-Western Zone (Upper Ecca) comprises alternating very fine-grained, feldspathic sandstone and mudrock or clastic rhythmite units. The formation thickness varies between 200 and 800 metres.
- The Tierberg Formation (Upper Ecca) is a predominantly argillaceous succession which reaches a maximum thickness of 700 metres along the western margins of the basin. It rests with a sharp contact on the Collingham or Whitehill Formations and grades up into the arenaceous Waterford or Adelaide

Formations. The bulk of the Tierberg Formation comprises well-laminated, dark grey to black shale. Clastic rhythmites occur at various levels in the sequence.

- The Skoorsteenberg Formation (Upper Ecca) is an arenaceous unit located between the Tierberg and Kookfontein Formations in the south-western part of the basin. It attains a maximum thickness of 200 metres, and comprises five sandstone-rich units up to 65 metres thick with shale units separating them.
- The Kookfontein Formation (Upper Ecca) overlies the Skoorsteenberg Formation with a sharp contact and grades upwards into the Waterford Formation. It is a lateral equivalent of the Tierberg Formation and attains a maximum thickness of 300 metres. The lower part of the formation comprises horizontally laminated dark-grey shales alternating with clastic rhythmites, which form minor upward-thickening cycles.
- Waterford Formation of the North-Western Zone formerly named the Carnarvon Formation (Upper Ecca) outcrops along the north-western Basin (Figure 4) and reaches a maximum thickness of 250 metres.
- The Pietermaritzburg, Vryheid and Volksrust Formations occur in the northern and eastern parts of the Karoo Basin and are not discussed.

4.1.3.3 Beaufort Group

The Beaufort Group sediments comprises of the Adelaide and Tarkastad Subgroups.

- The Adelaide Subgroup in the west comprises the Abrahamskraal, Teekloof and Balfour Formations. The Adelaide Subgroup comprises predominantly mudstone. The Teekloof Formation is characterised by a greater relative abundance of red mudstone compared to the underlying and overlying units, in practise the boundaries are linked to specific sandstone-rich marker units (members). The arenaceous Poortjie and Oudeberg Members constitute the base of the Teekloof and Balfour Formations, respectively. In the western basin the Abrahamskraal and Teekloof Formations attain thicknesses of 2,500 and 1,400 metres, respectively. The Balfour Formation attains a maximum thickness of 2,000 metres.
- The Tarkastad Subgroup in the central basin is characterised by a greater abundance of both sandstone and mudstone when compared to the Adelaide Subgroup. The subgroup has a maximum thickness of 2,000 metres and comprises a lower, sandstone rich Katberg Formation and an upper, mudstone rich Burgersdorp Formation. The sandstone and mudstone units of the Tarkastad Subgroup tend to form fining-upward cycles comparable to those of the Adelaide Subgroup.

4.1.3.4 Molteno Formation

The Molteno Formation attains a maximum thickness of 600 metres in the southern outcrop area. It comprises alternating medium-grained to coarse-grained, micaeous sandstones and grey mudrock, with sporadic coal seams.

4.1.3.5 Elliot Formation

The Elliot Formation comprises an alternating sequence of maroon and green-grey mudrock and sub-ordinate fine-grained to medium grained sandstone (yellowish grey to pale red) units. It attains a maximum thickness 500 metres.

4.1.3.6 Clarens Formation

The Clarens Formation represents the final phase of the Karoo sedimentation and consists mainly of wind-blown, fine-grained sandstone and siltstone. The Clarens Formation in the north is usually in the order of 100 metres thick. Minor basaltic lava flows, inter-layered with sandstone, occur in the upper most part of the Clarence.

4.1.4 Dolerite Intrusions

The Karoo Dolerite consists of an interconnected network of dykes and sills and it is not possible to single out any particular intrusive or tectonic event responsible for these intrusions. It, however, appears that a very large number of fractures within the Karoo lithology were intruded simultaneously by magma and that the dolerite intrusive network acted as a shallow "stockwork-like" reservoir (Woodford 2002).

The emplacement of dykes within the Western Karoo Basin appears to be lithologically controlled (Woodford 2002) where a decrease in intrusion density is noted at the boundary between the lower and upper Ecca. This boundary corresponds to the appearance of the first sandstone units in the Karoo Basin. The bulk of the dykes are strata bound and concentrate in the upper Ecca and Beaufort Groups (Adelaide and Tarkastad Subgroups), although some dykes are present in the lower Ecca and Dwyka Group. This indicates that the dykes propagate laterally along strike and not vertically (Woodford 2002).

4.1.5 Hydrogeology

Groundwater is generally viewed as a renewable resource because it is constantly being recharged from rainfall and surface water sources. In arid environments this is often not the case as recharge is limited. The hydrogeology of an area is determined by the ability of rocks to store and transmit water and the relationship between water bearing and non water bearing rocks.

Rock formations capable of yielding exploitable quantities of water to a borehole are known as Aquifers. In South Africa aquifers are defined as a geological formation, which has structures or textures that hold water or permit appreciable water movement through them (from National Water Act, Act No. 36 of 1998).

Formations with limited capacity to yield water to a well are called aquitards (areas of slow groundwater movement). Aquitards are defined as a saturated geological unit with a relatively low permeability that retards and restricts the movement of water, but does not prevent the movement of water.

Exploitable aquifers generally have a sustainable yield and good water quality i.e. potable water. The quality criteria for judging the suitability of water for different uses vary. For domestic use in South Africa water has to comply with minimum physical, chemical and bacteriological requirements as contained in SANS 241 (2005).

Water quality for drinking purposes is classified (SANS 241, 2005) into four quality categories, namely:

- Class 0: Ideal water quality-suitable for lifetime use;
- Class I: Good water quality-suitable for use, rare instances of negative effects;
- Class II: Marginal water quality-conditionally acceptable. Negative effects may occur in some sensitive groups; and
- Exceeding Class II (further subdivided by DWA into Classes 3 and 4): Poor water quality - unsuitable for domestic use without treatment. Chronic health effects may occur.

The electrical conductivity (EC, mS/m) is generally used as a primary indication of potable water quality (Vegter 1995). Limits of 70 and 150 mS/m represent potable water quality, categorized as Class 0 (<70mS/m) and Class1 (70 to 150mS.m). National water quality maps, based on the EC of groundwater (compiled by Vegter, 1995) indicate that groundwater quality in the Western Karoo Basin is generally within potable limits.

Apart from EC the chemical potability of groundwater has to be assessed in terms of the concentration of ions content. Of these fluoride and nitrate represent constituents that are most common present in concentrations exceeding the recommended limits of 1.0 mg/l F and 10 mg/l NO_3 (Vegter 1995). The fluoride water quality of Karoo aquifers associated with dolerite intrusions may contain elevated fluoride concentrations from geological origin (i.e. natural concentrations). The presence of excessive nitrate in aquifers may be an indication of pollution by concentrations of animal excrement in stock pens and at watering places or by sewage (Vegter 1995). Increased nitrate concentrations, due to stock watering, is especially noticeable in arid and semi arid areas with low rainfall recharge.

Groundwater occurrence within the Karoo sedimentary units within the shale exploration application areas has been described by Woodford in 2002. Reference is made to primary hydraulic properties of sedimentary

units and secondary aquifers related to fractured Karoo sediments and dolerite intrusions. In this text the descriptions have been divided into aquifers and aquitards.

- Aquitard 1. The Dwyka diamictite and shale have very low primary hydraulic conductivities and virtually no primary voids and are therefore aquitards. The Dwyka Group constitutes a very low-yielding formation and water is confined within narrow discontinuities such as jointing and fracturing. Since the Dwyka sediments were deposited mainly under marine conditions, water in these aquifers tends to be saline. Exploitable aquifers only exist in a few localities in the Basin where fracturing is significant. The folded Dwyka rocks in the Southern Karoo Basin are fractured to great depths, as evidenced by deep core-boreholes drilled in the 1960's (Woodford 2002).
- Aquitard 2A. The Ecca Group consists of mainly shales 1500 metres thick in the south. The shale porosity tends to decrease from 0.1% in the north to <0.02% in the southern and south-eastern parts of the Basin, while their bulk density increases from 2,000 to > 2,650 kg/m^3.
- Aquitard 2B. The sandstones of the Ecca Group have generally very low permeability, the main reason that the sandstone is poorly sorted and the primary porosity has been lowered considerably by diagenesis (i.e. the void spaces have been filled up).
- Aquifer 1. The Beaufort Group was deposited in a floodplain and the sedimentary units within it are heterogeneous (i.e. they can vary throughout the Group) resulting in a hydraulic layered system. Though locally variable, on average the rocks have very low primary permeability. The resulting hydraulic properties and responses to pumping of this aquifer are complicated. Pumping of a layered aquifer will cause the piezometric pressure in the more permeable layers to drop faster than in the less permeable layers. The life-span of a high yielding aquifer in the Beaufort Group is therefore limited if the aquifer is not recharged frequently.
- Aquifer 2. Zones of fracturing and weathering associated with dolerite dyke intrusions. Dolerite dykes are vertical to sub-vertical discontinuities that, in general, represent thin, linear zones of relatively higher permeability which act as a conduit for groundwater flow within the aquifer. They may also act as semi- to impermeable barriers to the movement of groundwater. The dykes are commonly expressed on the surface as a line of green bushes, which can readily be observed during the dry season. The contact zones of dolerite dykes have always been and remain the preferred drilling target for groundwater development in the Karoo.

The reasons that dolerite dykes are preferred for groundwater exploration are:

- There is an apparent higher probability of drilling a wet borehole in or next to a dyke than in the host rock away from the dyke; because the intrusion caused fracturing and subsequent weathering and enhanced hydraulic properties of the rock creating aquifers,
- Dykes are easily detected on remotely-sensed imagery, by relative simple geophysical techniques such as the magnetometer and are clearly visible to both the skilled and unskilled eye in the field,
- Dyke contact zones form linear aquifers characterised by relative higher permeability and lower storage. Their relatively simple and regular 3D geometry makes it easy to conceptualize and site an exploration borehole in the field, and
- Dyke contact zones are a cost effective groundwater target, (high success rate).

The zone of contact metamorphism (distance away from a dyke the host rock is metamorphosed and jointed) affects the yield of a borehole drilled into this zone. The highest borehole yields are obtained within 1 to 5 metres of the dyke contact. There are instances where the dyke itself is water bearing. The dyke-sill contact zone is generally not as wide or permeable as that of the dyke-sediment contact.

In the study by Kirchner and van Tonder (1991) the exploitation potential of Karoo aquifers was defined as the long-term yield of an aquifer which depends on recharge due to rainfall, underground in- and outflow and groundwater storage.

The occurrence of groundwater in Karoo Rocks was briefly described by Kirchner and van Tonder (1991) as follows:

- The permeability of fresh, non-fractured, joint free Karoo sedimentary rocks is generally in the order of 10^{-8} m/s and less. With the exception of a few sandstones, this applies to the whole range of argillaceous to arenaceous types, comprising the Karoo Sequence – diamictite, shale, mudstone, siltstone, arkose, greywacke and sandstone.
- Karoo strata owe their water-bearing properties to the fracturing which is generally limited to the top 30 metres or so below the surface. Weathering processes play an essential role in opening incipient fractures/joints and in converting the rocks into more porous media. Groundwater occurrence is therefore almost entirely controlled by the development/presence of secondary permeability within the rock mass
- Well jointed zones of sedimentary rocks also occur in association with kimberlite or lamprophyre dykes and pseudo-coal veins in the south.
- Gentle folding in the far south has resulted in more or less uniform well-jointed strata, affording zones of secondary permeability within the rock mass.
- Karoo aquifers have small storage cavities, owing to the low storativity as well as the small thickness. The most productive aquifers are found where water-bearing alluvial deposits overlie the fractured and weathered strata.
- Except for a belt of gently folded strata in the far south, the Main Karoo Basin has been extensively intruded by dolerite dykes and inclined and undulating dolerite sheets or sills. These intrusive are hydrogeologically very important as they are associated with the more prolific water-yielding structures. These are:
  - Weathered and jointed sedimentary rock alongside dykes.
  - Weathered and fractured dolerite dykes.
  - Weathered and fractured upper and lower contact zones of dolerite sheets or sills.

The role of storage-dependant recharge in Karoo aquifers and implications of borehole water-strike frequency analysis is commented on by Vegter (1995) as follows:

- A special case of storage-dependant recharge is that of "dual porosity" formations such as Karoo sedimentary rocks. Permeable open fractures in these formations may fill up rapidly under favourable recharge conditions whilst the uptake of water from the open fractures into adjacent pores and micro-fractures is slow. The result is incomplete recharge of available storage space. Complete replenishment of the available storage space may only be realised during a prolonged period of rainfall.
- The frequencies with which water was struck in boreholes at different depths below the groundwater level have been analysed statistically. Strike frequencies were calculated in terms of the number of holes which passed through a particular 10 metre section below the water level and not in terms of the total number of holes. A strike frequency graph was compiled for Karoo sedimentary rocks. The strike frequency graph indicates an initial increase which is interpreted as an indication of saturated decomposed rock in a certain percentage of holes. The strike frequency for Karoo rocks peak (0.46) around 10 metres below the water level, reducing rapidly to 0.25 at 20 metres and thereafter to 0.08 at 50 metres. From 50 to 90 metres the strike frequency remains in the order of 0.08 possibly due to fractured sandstones at depth. The strike frequency analysis for the Karoo rocks indicates a predominant shallow groundwater occurrence, mostly in the first 50 metres below the water table.

4.1.6 Deep Core Boreholes

Information on the geology and hydraulic properties of the Karoo strata below the depth of normal groundwater development (generally <150m, locally possibly up to 300m), is sparse. However, in the late 1960's deep core holes were drilled in the Southern Karoo Basin. These deep core holes have provided some insight into the hydraulic properties of the deep strata of the Basin. In addition to the discussion in Woodford & Chevallier (2002) four of the deep well completion reports have been reviewed and findings can be summarised as:

- In one instance well cemented Lower Beaufort (Adelaide Subgroup) sandstone and siltstone and blocky mudstones were intersected to depths of 2 137m followed by massive shale and tight siltstone and sandstone of the Ecca Group. Below 3 782m massive Dwyka tillite was intersected to 4 291m underlain by Bokkeveld Shale. Some fracture/joint zones are reported with water. The largest water flow of 0.8 l/s is reported from fractured tillite at the base of the Dwyka. The sedimentary sequence was characterised by an absence of primary porosity.
- A deep core hole was drilled to 2 600m. All sandstone intersections are reported tight. Mud losses are reported in shale which could imply some jointing or fracturing. Geophysical logs run in the hole indicated no development of porosity or permeability. It was concluded that the entire formation was very tight.

The available information has confirmed that the permeabilities of the sandstone/siltstone penetrated by the deep core holes in the Southern Karoo Basin are very low, and vary from 0.00 – 2 m/d for Beaufort strata and 0.00 – 0.1m/d for Ecca strata (Woodford & Chevallier, 2002). Secondary porosity is present in fracturing within the rock mass, as evidenced by the occasional presence of water and mud losses. Overall however, the deep core logs have confirmed that the vast majority of the deep Karoo sequence is composed of tight and cemented strata.

4.2 Overview of the Western Precinct

The regional hydrogeology setting of the Western Precinct is discussed with reference to the 6 maps (Maps W1 to W6) presented in Attachment A.

Groundwater resources are generally locally available and utilised in small quantities, occur at shallow depths and vulnerable to overexploitation and drought.

4.2.1 Regional Geology

4.2.1.1 Lithology

The geology shown in Map W1 was compiled using the simplified geology of South Africa (DWA) with the dolerite sills and dykes obtained from the published 1: 250 000 scale geological maps superimposed on the map. The main Karoo sediments that occur in the precinct include the Beaufort and Ecca Group lithologies. The Beaufort Group comprises the Adelaide Subgroup. In the north-western parts of the precinct Ecca Group sediments of the Waterford Formation are present.

- The Adelaide Subgroup covers the entire southern and south eastern portion of the precinct. The subgroup comprises predominantly mudstone and is underlain by the Ecca Group. The Teekloof Formation is characterised by a greater relative abundance of red mudstone compared to the underlying and overlying units; in practise the boundaries are linked to specific sandstone-rich marker units (members), The arenaceous Poortjie and Oudeberg Members constitute the base of the Teekloof and Balfour Formations, respectively and often form sandstone ridges, as illustrated on Figure 5. In the western basin the Abrahamskraal and Teekloof Formations attain thicknesses of 2,500 and 1,400 metres, respectively. The Balfour Formation is not present.
- The Waterford Formation (Upper Ecca) formerly named the Carnarvon Formation outcrops in the north eastern area. It reaches a maximum thickness of 250 metres. The sediments consist of a sequence of interbedded fine- to very-fine grained tabular sandstones up to 8 metres thick, siltstone, shale and rhythmite, Figure 6. The different facies form upward-coarsening sequences ranging in thickness from 4 to 38 metres.
- The precinct is characterised by horizontal to quasi-horizontal strata. The horizontal bedding gives rise to the wide expansive landscape of flat to gently undulating plateau as shown in Figure 7 and Figure 8.
- Dolerite intrusions, in the form of sills and dykes, occur in abundance throughout the Western Precinct, as shown on W1. The dolerite intrusions, (dykes and sills) represent the main targets for groundwater exploration. The high ridges which characterise large parts of the precinct are the result of erosion resistant dolerite forming cappings to these features, as illustrated in Figure 9. A good exposure of a typical dolerite dyke is illustrated in Figure 10.

Figure 5: Typical Sandstone Ridge

Figure 6: Horizontally bedded sandstone, siltstone and shale

Figure 7: Characteristic siltstone plateau landform

Figure 8: Plateau formed on Dolerite sill

Figure 9: Typical dolerite capped ridge, siltstone plateau in foreground

Figure 10: Dolerite Dyke

4.2.1.2 *Regional Structure*

The distribution of intruded dykes in the Main Karoo Basin forms three major structural domains, namely the Western, Eastern and Transkei-Lesotho-Northern Karoo Domains, (Woodford 2002). The Western Karoo Domain extends from Calvinia to Middelburg, and covers the entire Western Precinct area. It is characterized by two distinctive structural features:

- E-W Dyke Intrusions

Some of these dykes are extensive and continue over 500 km. They were intruded along major lateral E-W dislocation/shear zones and are accompanied by NW and NE trending sympathetic shears.

- NNW Dyke Intrusions

These are also extensive and are regularly spaced from east to west across the domain. The trend of these dykes varies along the trajectory, curving from WNW in the south to NS in the north.

Only limited fault zones are indicated on the published 1:250 000 scale geological maps of the precinct. These zones have similar trends to the dykes and form part of the Western Karoo Domain.

4.2.2 Groundwater Occurrence and Borehole Yield

The hydrogeology shown in Map W2 was compiled from the published hydrogeological map series at 1:500 000 scale by DWA, dated 1996 to 2003.

This indicates that precinct is dominated by the fractured aquifer type. The borehole yield prospect in the precinct is generally between 0.5 to 2.0 l/s. In the NW corner the borehole yields are less and vary between 0.1 – 0.5l/s.

Intergranular and fractured aquifer types are shown to be present as patches throughout the precinct. The borehole yield mostly ranges from 0.1 to 0.5l/s, with yields of 0.5 0 2l/s in the northern portions of the precinct.

4.2.3 Borehole Drilling Depth

The borehole distribution and drilling depths presented in Map W3 were compiled from the NGDB borehole database of DWA, dated 2008. The borehole distribution indicates that groundwater is widely used in the precinct, with an abundance of records in the NW in the Williston area, and in the East eats of Fraserburg and south of Loxton. The central zone of the precinct is characterised by little reported groundwater use.

Information on the drilling depths of 1896 boreholes was available. The depth ranges have been categorised into 5 depth intervals. These intervals are depicted in Map W3 and summarized Table 1 below:

Table 1: Summarised drilling depths in the precinct

Depth Range (metres)	Total number of records	Percentage of Total
0 – 50	1298	68.5
50 – 100	472	24.9
100 – 150	78	4.1
150 – 200	26	1.4
200 – 300	22	1.2

The drilling depths in the precinct indicate the majority (>68 %) boreholes abstract water from depths less than 50 metres. Table 1 also indicates that very few (<6%) boreholes abstract water from depths in excess of 100 metres, these mostly relate to drilling undertaken by DWA to locate deeper water bearing strata.

4.2.4 Depth to Water Level

The depth to groundwater levels presented in Map W4 was compiled from the NGDB borehole database from DWA, dated 2008.

Information on the water level depths of 2014 boreholes was available. The depth ranges have been categorised into 7 depth intervals. These intervals are depicted in Map W4 and summarized in Table 2.

Table 2: Summarised depths to water level in the precinct

Depth Range (metres)	Total number of records	Percentage of Total
0 – 10	1098	54.5
10 – 20	564	28.0
20 – 30	203	10.1
30 – 82	108	5.4
50 – 75	33	1.6
75 – 100	8	0.4
>100	0	0.0

The distribution of water level depths indicates that shallow water level conditions of <30m are generally (~92%) present throughout the precinct. This indicates that sustainable groundwater exploitation relies mainly on recharge from rainfall and the storage potential of the aquifer at shallow depths.

4.2.5 Water Quality (EC)

The electrical conductivity (EC) data presented in Map W5 was compiled from the Water Quality Management System (WQMS) database from DWA, dated 2008. This information has been plotted on the published EC zone map of DWA.

Information on the electrical conductivity of water from 1276 boreholes is available. The EC ranges have been categorized in 5 water quality classes as used by DWA. These intervals are depicted in Map W5 and summarized in Table 3 below:

Table 3: Distribution of water quality (EC) in the precinct

EC Range (mS/m)	Total number of records	Percentage of Total
0 – 70 Class 0	93	7.3
70 – 150 Class 1	940	73.7
150 – 370 Class 2	205	16.1
370 – 520 Class 3	15	1.2
>520 Class 4	23	1.8

The distribution of the EC indicates that potable water suitable for domestic use (Class 0 and Class 1) is largely (81 %) available throughout the precinct. Approximately 16% of the water is brackish (Class 2) and 3% can be classified as saline (Class 3 and 4) and unsuitable for human consumption.

4.2.6 Registered Water Use

The water use sector is listed for all registered water use on the Water Authorization and Registration Management System (WARMS) maintained by DWA. Two water use sectors, agriculture (stock watering and irrigation) and domestic comprise the main water users in the precinct. The annual water use registration for these sectors has been categorized in 5 volume intervals and the use distribution is presented in Map W6.

The annual registered groundwater use for the precinct is summarised Table 4 below:

Table 4: Registered agricultural and domestic use in the precinct

Water Use Sector	Number of Users	Annual Use (million m^3)
Domestic	None Registered	0.0
Agriculture (Stock and Irrigation)	147	4.571

It is clear from the above and Map W6 that groundwater is mainly used for agricultural purposes. The total annual agricultural use is 4.571 million m^3. Domestic water is potentially underestimated since town water supplies are possibly not updated on WARMS.

4.3 Field Verification

The overview verification involved travelling through the precinct covering as much of the precinct area as practical within the limited time available. The spatial distribution of the areas visited within the precinct is illustrated on Figure 11.

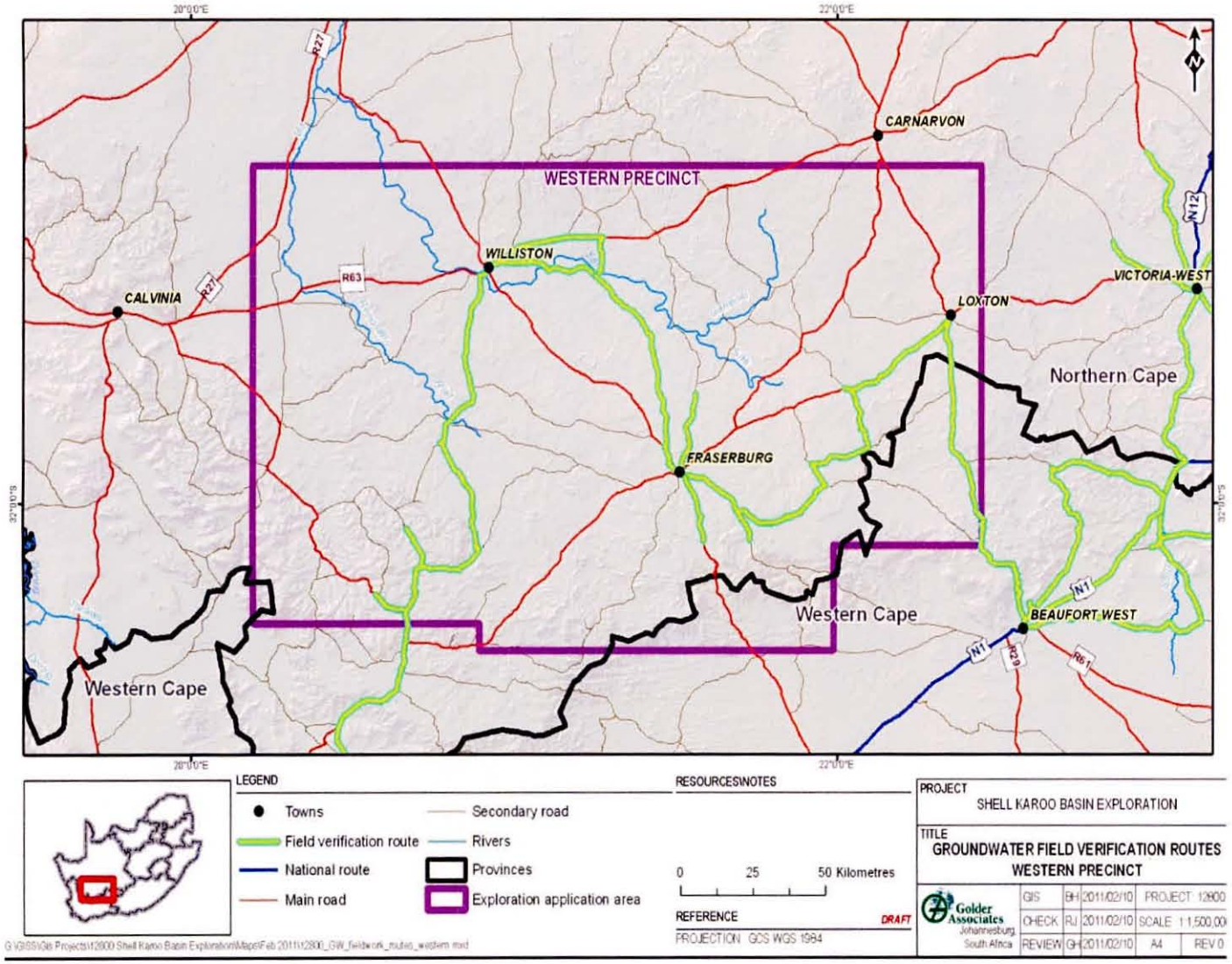

Figure 11: Field Verification Route

Groundwater use is almost entirely for agriculture, mostly stock watering and for homestead supply. The use of wind pumps (Figure 12 and Figure 13) may indicate limited abstraction capacity since the average yield of the wind pumps is usually 0.3l/s and therefore a maximum daily volume of around 26m³ can be achieved.

Farm homesteads are often supplied by 3-5 wind pumps. These are commonly located on the margins of dolerite dykes and/or sills. Some homestead supply boreholes are likely to be equipped with motorised pumps. One small irrigation area supplied by wind pumps was seen during the verification, this is shown on the cover photograph and Figure 14.

Figure 12: Typical windpump edge of sandstone ridge

Figure 13: Typical windpump on dolerite dyke

Figure 14: Irrigation from Groundwater

The visit provided the opportunity to verify the regional geological setting, particularly in respect to the occurrence of groundwater.

- As noted above, the area is characterised by quasi-horizontal strata. This is important to the gas exploration programme since the horizontal strata provides a capping and protection to the shale gas reservoirs present at depths between 1 500m and 4 500m depth.
- Dolerite sills often form capping to hills, due to their increased resistance to weathering and erosion.

- The wide expansive plains are controlled by the horizontal bedding and are formed on dolerite sills or siltstone horizons.
- Groundwater occurrence is mostly controlled by the presence of dolerite dykes, where the fractured contact zones with the country rock offer enhanced permeability, with the upper contact zones of dolerite sills where these are relatively shallow and do not form cappings to hills or ridges, fracture zones and weathering and fracturing of sandstone, siltstone and shale where these strata form topographic lows, along drainage lines for example.

5.0 UNCONVENTIONAL GAS EXPLORATION DRILLING

A brief overview of the drilling procedures for unconventional gas exploration provides the context for the technical assessment of a hypothetical typical gas exploration well discussed in section 6.

5.1 Gas Exploration Well Construction Design

This section briefly describes the construction design of the gas exploration well. An example of a gas exploration drilling rig is given in Figure 15.

The well is drilled using drilling fluids (drilling muds). These muds are recirculated and keep the drilling bit cool and lubricated, remove the drilling cutting and provide a positive hydraulic head to prevent ingress of groundwater into the well during drilling. The drilling muds are contained on surface in tanks.

Typically the well is drilled vertically through the shallow groundwater bearing zones. Once these have been penetrated, to a depth of between ±100 and ±300m the drilling bit and rods are withdrawn and the well is completely cased with plain steel casing. This casing is then cemented in place by pressure grouting from the base of the hole to force cement up between the casing and the drilled diameter to fill the annulus. This ensures the groundwater zones are isolated from the well and there is no connection between the well and the surrounding groundwater (if any is present). Once the cement has set the integrity of the cementing job is verified using down hole logging techniques. This is of importance since no exchange of fluids or gas must take place in the annular space nor enter the well.

Figure 15: Example of a gas exploration drilling rig

Multiple casing columns are installed at various depths during the well construction. Each casing column is pressure grouted and the integrity of the grouting is verified as mentioned above. Typically the following casing columns are used:

- Conductor casing: during the first phase of drilling, a shallow steel conductor casing is installed vertically to reinforce and stabilise the ground surface;
- Surface casing: after installation of the conductor casing, drilling continues to the bottom of freshwater aquifers (depth requirements for groundwater protection vary according with the local hydrogeological conditions), at which point a second casing (surface casing) is inserted and cemented in.
- Intermediate casing (not usually required): a third (intermediate) casing is sometimes installed from the bottom of the surface casing to a deeper depth. This is usually only required for specific reasons such

as additional control of fluid flow and pressure effects, or for the protection of other resources such as minable coals or gas storage zones.

- Production casing: after the surface casing is set (or intermediate casing when needed), the well is drilled to the target formation and a production casing is installed either at the top of the target formation or into it (depending upon whether the well will be completed "open- hole" or through perforated casing).

Vertical drilling is continued through the cement plug which forms at the base of the initial hole and casing to a depth determined by the anticipated depth of the target shale horizon, this could be between approximately1 500m and 4 500m. Since the target shale horizons are expected to be a few 10's of metres thick, a downhole drilling motor is positioned in the hole to enable angled and then horizontal drilling advance. Drilling continues as normal and the horizontal section of the hole is continued as determined necessary through the target shale.

Once the hole has been completed to the required depth and horizontal length, the drill string is withdrawn and the entire length of the hole is cased with plain steel casing. This casing is designed to with stand the pressures encountered at depth. Once installed the casing is cement grouted in place using high pressure grouting techniques to fill the annulus and thus prevent leakage of gas, water and chemicals around the casing. Once again the integrity of the cementing job is verified.

Once the grouting has been completed the drilling rig is removed and hydrofracturing equipment set up, (if hydraulic fracturing is to be undertaken).

The design of the gas exploration well is illustrated on Figure 16. This shows the plain steel casing installation and cement grout.

5.2 Hydraulic Fracturing

Once the gas exploration well has been completed the well may be subject to hydraulic fracturing to stimulate the flow of gas from the shale reservoir.

Hydraulic fracturing is a process that makes it possible to recover natural gas from low permeability formations where the rock is unusually densely packed. As an example the natural compaction of the rock mass at 3000m below surface is at least 300bars (lithostratigrafic pressure). The oil and gas industry has been using hydraulic fracturing since the 1940s. It now plays a role in the development of natural gas resources around the world. This technique has also been used in the groundwater industry to increase yields in boreholes drilled in low permeability formations.

Hydraulic fracturing is the process of creating fissures, or fractures, in underground formations to allow natural gas to flow. Once a well has been drilled, Shell will study a range of variable factors such as the nature of the rock formation and the thickness of the targeted area before starting hydraulic fracturing. Not all wells drilled are fractured, for example the formation may be sufficiently permeable to allow gas to flow into the well without the need for hydraulic fracturing.

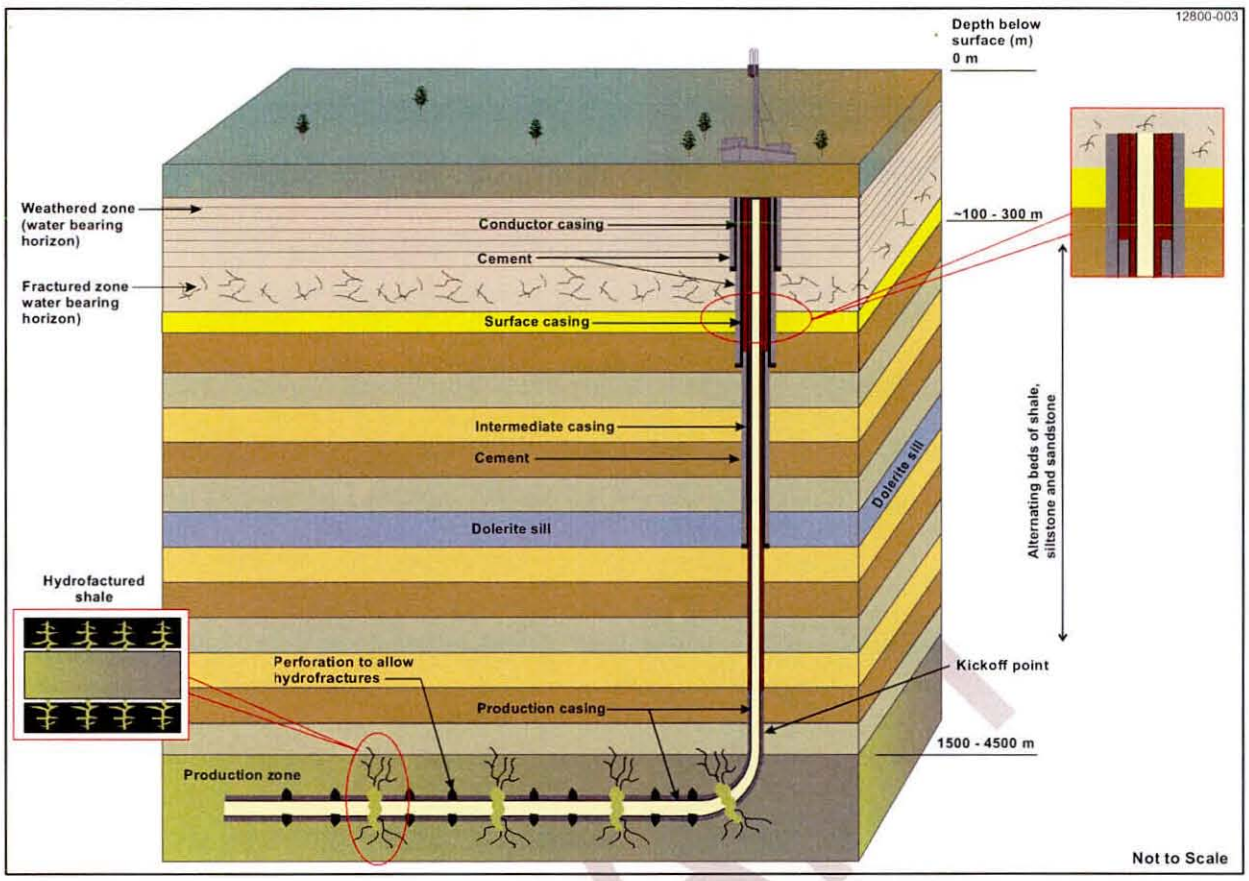

Figure 16: Schematic Design of Gas Exploration Well Construction

The formations in the Karoo that are believed to contain recoverable gas lie several thousand metres (1 500m to 4 500m) below the surface, this is well below any fresh groundwater aquifers which, as discussed earlier, mostly occur at depths of between 50 – 100m, and possibly locally up to 300m depth. Shell does not carry out production or fracturing in fresh groundwater aquifers. Between approximately 1 200 metres and 4 200 metres of horizontally bedded rock separates the natural gas formations from the groundwater aquifers providing protection. As described in section 5.1 protective steel casing embedded in cement that is specifically designed and installed to protect the fresh-water aquifers is installed in the well.

Once a decision to carry out hydraulic fracturing has been made, a casing perforator tube and perforating gun is positioned in the horizontal section of the well. The well is perforated by punching through the casing and cement grout at intervals using the perforating gun and an electrical charge.

The hydraulic fracturing operation involves the pumping of water, proppant (for example sand) and other additives under high pressure into the productive shale formation to create fractures. The fluid consists of more than 99% water and proppant, along with a small amount of special-purpose chemicals. The proppant props open the fractures formed and thus prevents closing up of the newly created fractures, allowing the gas to flow into the wellbore and to the surface. The chemicals used are selected on the basis of the rock type intersected at the intended fracturing section.

A fracture length can be up to several hundreds of metres. The fracturing process ensures that the fractures are contained within the boundaries of the targeted geological formation.

Fracturing operations typically take 2 weeks per well and require a crew of between 15 to 20 people. A hydraulic fracturing operation normally only takes place only once in the life of an exploration well.

A view of a typical hydraulic fracturing surface set up is given in Figure 17. The horizontal section where hydraulic fracturing occurs is illustrated on Figure 16.

Figure 17: Typical surface set up for Hydraulic Fracturing

Environmental impacts relating to hydraulic fracturing involve the introduction of contaminants into aquifers via fractures created by the hydraulic fracturing process linking the target shale gas reservoir with the overlying groundwater aquifers. Andrews et al. (2009) report that hydraulic fracturing does induce new fractures into the shale, which can propagate long distances along the bedding planes of the shale formation. The potential for propagating fractures into an overlying aquifer may depend upon the depth separating the two, the rock type and the angle of the bedding. Andrews et al. also state that engineers designing and conducting the hydraulic fracturing have a strong incentive to limit the fractures to the height of the gas producing shale zones. Wood et al; (2011) note that fractures start at the injection well and extend as much as a few hundred metres into the reservoir rock. Arthur and Bohm (2008) reported that fracture design involves sophisticated procedures to accomplish an effective, economic and successful job. The techniques available include computer simulation models which can simulate 3D fracture geometry. Such "hydraulic fracturing models allow the geologists and engineers to modify the design of a design of a hydraulic fracture treatment and evaluate the height, length and orientation of potential fracture development prior to the initiation of the actual fracture treatment.

The type of fracturing fluid to be used in the project has not yet been identified. The potential impacts relating to the fracturing process will depended on the nature of chemical additives used in the fluid. Certain types of fracturing fluids used in the industry contain chemicals that, if used at high enough concentration, can potentially contaminate the environment. The US Environmental Protection Agency (US EPA) has launched a research programme to improve understanding of this risk (timetabled to provide initial results towards the end of 2012). The actual fracturing fluid to be used will be identified and the impacts relating to the fracturing process will be assessed as part of the environmental impact assessment carried out during the next phase of the project.

The depth of shale gas extraction gives rise to major challenges in identifying categorically pathways of contamination of groundwater by chemicals used in hydraulic fracturing process. In terms of the technical assessment the key criteria to consider are the depth of hydraulic fracturing and the status of the intervening lithology (rock types) between the shale reservoir and the groundwater zone.

5.3 Water Supply

Water is required for the drilling and hydraulic fracturing operations. If hydraulic fracturing is undertaken the volume of water required will be 2 000 – 4 000m^3 for each well, considerably less water is needed should drilling only be required.

At this stage a range of options are being considered; these include groundwater and other sources. Shell will not use groundwater for gas exploration until a detailed hydrogeological study of the target drilling areas has been completed and a risk mitigation plan in place.

5.3.1 Groundwater

If it is decided that groundwater is a potential supply source the water supply could be obtained from the general vicinity of the gas well site. The groundwater supply would be obtained from dedicated water supply boreholes sited to exploit potentially brackish or saline quality water, i.e., groundwater unsuitable for domestic or livestock use, occurring below the main potable aquifer. The target aquifers are therefore deep water bodies probably at depths greater than 100 to 300m.

It is noted in section 4.2.5 that Class 3 and 4 water, unsuitable for potable use, is recorded for 4.4% of the boreholes in the precinct for which information is available. It is possible therefore that suitable poor quality could be sourced from boreholes shallower than 150m.

The water supply would be obtained from a wellfield specifically sited and drilled to supply the well site with water. These boreholes would be positioned within a reasonable distance of the well site and would be the subject of a specialized survey to locate suitable target aquifers. It is probable that groundwater sources to be developed for once-off use during the exploration phase could generally be developed within a 10 km radius of the well.

The water supply boreholes will need to be correctly constructed with steel casings and sanitary seals to prevent any surface contaminants entering the groundwater via the borehole annulus. It will also be important that any new boreholes are sited at an appropriate distance from existing boreholes to minimise impacts. Should the need arise to understand the radius of influence of exisiting boreholes, it will be determined on a site by site basis.

The study has indicated that the yield of most boreholes drilled in the precinct is between 0.5 and 2l/s. Accordingly 2 – 3 boreholes could be required for each exploration site to deliver up to 4 000m^3 within a period of approximately 1 month. Adequate storage will accordingly be required at the well site, since the hydraulic fracturing process is estimated to use this volume of water over a period of 1 – 2 weeks.

5.3.2 Other Sources

Where boreholes prove to be not feasible or the yield is insufficient to supply the water required for the exploratory wells other sources of water would need to be considered. Such sources could include:

- Treated waste water;
- Pumping from a suitable surface water sources inside or outside the area such as a suitable large dam;
- Using seawater;
- Purchase from a local municipality.

Water obtained from these sources would be trucked to site in water tankers.

6.0 TECHNICAL ASSESSMENT

The preliminary technical assessment discussed in this section relates to a hypothetical gas exploration well. No sites have been selected as yet, and no gas exploration drilling will commence prior to the undertaking of a detailed site assessment and groundwater technical assessment as part of the required EIA. Furthermore it is noted that the assessment is discussed for the case of an exploration well which is an isolated event. Accordingly, potential risks, impacts and mitigation measures apply for an isolated occurrence and may not be sufficient for a situation when cumulative aspects need to be considered (well field type development).

6.1 Gas Exploration Well activities that could potentially impact the groundwater environment

Potential impacts to the groundwater could result from the following.

6.1.1 Site preparation

- Construction of the well pad leading to minor reduction in groundwater recharge;
- Leakage of stored (poor quality) water on site leading to deterioration of groundwater quality at the site;
- Leakage of stored drilling fluids and chemicals leading to deterioration of groundwater quality at the site; and
- Geophysical data acquisition using Magneto-Tellurics surveying which will disturb a small area of soil at the surface for a short period of time.

6.1.2 Exploration drilling and hydraulic fracturing

This covers the drilling and possible hydraulic fracturing of the hypothetical gas exploration well

- Storage tanks leak/collapse/burst leading to potential impact to the aquifer;
- Pumps/pipes to/from storage tanks to wellhead fail resulting in spillage and seepage to groundwater;
- Intersection of aquifers can provide a flow path which can result in a loss of groundwater to deeper zones, impacting on groundwater levels;
- Intersection of deep saline water bearing zones providing a flow pathway resulting is saline water rising to rising towards the surface and impacting on the shallower aquifers;
- Intersection of significant fracture zone and the well could therefore provide a pathway for groundwater loss to the fractured zone or potentially contamination by saline water contained in the fracture rising to the surface and impacting on the shallower aquifers;
- Failure of steel well casing and cement grout to provide complete seal with aquifer and leaking of groundwater into the annulus;
- Failure of steel casing to provide complete seal with hydraulic fracturing zone and leakage of gas and chemicals into the well annulus and subsequently into the overlying aquifers;
- Hydraulic fracturing of the well leading to invasion of chemicals from the target shale horizon into the overlying aquifers via minor fracture zones;
- Larger volume than expected of return water from the gas exploration well resulting in the return water storage dam filling and overflowing and/or spillage of saline/brackish return water from the well causing contamination of the underlying groundwater;
- Leakage and spillage of stored chemicals causing impact of the underlying groundwater
- Inflow of groundwater from shallow aquifers into the well causing a lowering of water levels and loss of capacity of nearby stock watering/farm boreholes; and
- Abstraction of groundwater for water supply to the drilling and hydraulic fracturing operations could potential result in lowering of the groundwater level near the wells and impact on neighbouring groundwater users or groundwater springs.

6.1.3 Decommissioning

- Leakage and spillage of contaminated water on site leading to impact of groundwater
- Leakage and spillage of stored chemicals leading to impact of groundwater;
- Spillages and residues during and after site cleanup;
- Leakage and spillage of contaminated water during transport to selected disposal site;
- Inadequate sealing of well resulting in poor sealing of gas and contaminated hydraulic fracturing water and subsequent invasion of the well and contamination to groundwater aquifers; and
- Inadequate sealing of water supply boreholes leading to aquifer contamination.

6.2 Description of the technical assessment methodology

The potential significance of impacts is based on occurrence and severity, which are further sub-divided as follows:

Occurrence		Severity	
Probability of occurrence	Duration of occurrence	Magnitude (severity) of impact	Scale / extent of impact

To assess each impact, the following four ranking scales are used:

PROBABILITY	DURATION
5 - Definite/don't know	5 - Permanent
4 - Highly probable	4 - Long-term
3 - Medium probability	3 - Medium-term (8-15 years)
2 - Low probability	2 - Short-term (0-7 years) (impact ceases after the operational life of the activity)
1 - Improbable	1 – Immediate
0 - None	
SCALE	**MAGNITUDE**
5 - International	10 - Very high/don't know
4 - National	8 - High
3 - Regional	6 - Moderate
2 - Local	4 - Low
1 - Site only	2 - Minor
0 - None	

The significance of the two aspects, occurrence and severity, is assessed using the following formula:

SP (significance points) = (probability + duration + scale) x magnitude

The maximum value is 150 significance points (SP). The impact significance will then be rated as follows:

SP >75	Indicates **high** environmental significance	An impact which could influence the decision about whether or not to proceed with the project regardless of any possible mitigation.
SP 30 – 75	Indicates **moderate** environmental significance	An impact or benefit which is sufficiently important to require management and which could have an influence on the decision unless it is mitigated.
SP <30	Indicates **low** environmental significance	Impacts with little real effect and which should not have an influence on or require modification of the project design.
+	Positive impact	An impact that is likely to result in positive consequences/effects.

6.3 Technical Assessment: Site Preparation and Magneto-Telluric Survey

Table 5 below summarises potential groundwater impacts directly related to Magneto-Telluric Surveys and site preparation of a hypothetical gas exploration well, and provides a significance rating for each impact before and after mitigation.

Table 5: Preliminary Groundwater Technical Assessment Matrix for the proposed South Western Karoo Basin Gas Exploration Application Project – Site preparation and Magneto-Telluric Surveys

PRELIMINARY ASSESSMENT OF	ENVIRONMENTAL SIGNIFICANCE	
	Before mitigation	**After mitigation**

POTENTIAL GROUNDWATER IMPACTS	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Geophysical data acquisition using Magneto-Tellurics surveys	2	1	0	0	0	Low	2	1	0	0	0	Low
Construction of the well pad leading to reduction in groundwater recharge	2	1	1	4	12	Low	2	1	1	2	8	Low
Leakage of stored (poor quality) water on site leading to deterioration of groundwater quality at the site	4	2	2	2	24	Low	2	2	1	2	10	Low
Leakage of stored drilling fluids and chemicals leading to deterioration of groundwater quality at the site	4	2	2	2	24	Low	2	2	1	2	10	Low

6.3.1 Reduction in groundwater recharge

Technical assessment

Construction of the well pad will result in reduction of recharge to the groundwater over the well pad area.

Mitigation measures

Impacts can be minimised by directing clean storm water runoff off the well pad to a soakaway.

Impact significance

It is anticipated that the well pad will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.3.2 Leakage of stored (poor quality) water

Technical assessment

Poor quality water may be stored on site. Leakage and/or spillage of this water could result in groundwater contamination.

Mitigation measures

Ensure all water storage containers are located on the well pad. Water storage containers must be robust and not overfilled. Area to be bunded to contain any spillage.

Impact significance

It is anticipated that spillage of water will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.3.3 Leakage of stored drilling fluids and chemicals

Technical assessment

Drilling fluids and chemicals may be stored on site. Leakage and/or spillage of could result in groundwater contamination.

Mitigation measures

Ensure all storage containers are located on the well pad. The storage containers must be robust and not

overfilled. Area to be bunded to contain any spillage. Personnel to be inducted into correct and careful handling of drilling fluids and chemicals. Suitable intervention and cleanup plan must be in place and clean up facilities available on standby.

Impact significance

It is anticipated that spillages will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.3.4 Geophysical data acquisition using Magneto-Tellurics Surveying

Technical assessment

The geophysical survey involves non invasive surface techniques. No impacts to the groundwater regime are anticipated.

Mitigation measures

None.

Impact significance

It is anticipated that the geophysical surveying will result in no impacts.

6.4 Technical Assessment: Exploration drilling and hydraulic fracturing

Error! Reference source not found. below summarises potential groundwater impacts directly related to exploration drilling and hydraulic fracturing of a hypothetical gas exploration well, and provides a significance rating for each impact before and after mitigation. Activities involve the drilling of the gas exploration well possibly followed by hydraulic fracturing.

6.4.1 Water storage tanks leak/collapse/burst

Preliminary Technical assessment

Poor quality water may be stored on site. Leakage and/or spillage of this water could result in groundwater contamination.

Mitigation measures

Ensure all water storage containers are located on the well pad. Water storage containers must be robust and not overfilled. Area to be bunded (contained) to contain any spillage.

Table 6: Preliminary Groundwater Technical Assessment Matrix for the proposed South Western Karoo Basin Gas Exploration Application Project – Exploration drilling and hydraulic fracturing

PRELIMINARY ASSESSMENT OF POTENTIAL GROUNDWATER IMPACTS	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Water storage tanks leak/collapse/burst leading to contamination of aquifer	4	1	2	2	20	Low	2	1	1	2	8	Low
Pumps/pipes to/from storage tanks to wellhead fail resulting in spillage	4	2	2	2	24	Low	2	2	2	1	10	Low
Leakage of stored drilling fluids and chemicals leading to deterioration of groundwater quality at the site	4	2	2	2	24	Low	2	2	1	2	10	Low
Intersection of aquifers	8	5	1	4	80	High	2	5	1	1	14	Low
Intersection of deep saline aquifers	4	1	2	2	20	Low	2	1	2	2	10	Low
Intersection of significant fracture zone	4	1	2	2	20	Low	2	1	2	2	10	Low
Failure of steel well casing and cement grout to provide complete seal with aquifer and leaking of groundwater into the annulus	4	1	1	2	16	Low	4	1	1	1	12	Low
Failure of steel well casing and cement grout leading to leakage of contaminated water and chemicals from well into the groundwater aquifer	6	2	2	1	30	Moderate	4	2	1	1	16	Low
Failure of steel casing to provide complete seal with hydraulic fracturing zone and leakage of gas and chemicals into the well annulus and subsequently into the overlying aquifers	6	2	2	1	30	Moderate	4	2	1	1	16	Low
Hydraulic fracturing of the well leading to invasion of chemicals from the target shale horizon into the overlying aquifers via unknown fracture zones	8	2	2	1	40	Moderate	4	2	2	1	16	Low
Larger volume of return water from the gas exploration well than expected resulting in the return water storage dam filling and overflowing and/or spillage of saline/brackish	6	2	2	3	42	Moderate	4	1	1	1	12	Low

PRELIMINARY ASSESSMENT OF POTENTIAL GROUNDWATER IMPACTS	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
return water from the well causing contamination of the underlying groundwater												
Inflow of groundwater into the well causing a lowering of water levels and loss of capacity of nearby stock watering/farm boreholes	6	2	2	2	36	**Moderate**	2	1	1	1	6	**Low**
Abstraction of groundwater for water supply to the drilling and hydraulic fracturing operations	6	4	3	3	60	**Moderate**	2	2	2	2	12	**Low**

Impact significance

It is anticipated that spillage of water will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.4.2 Failure of pumps/pipes to/from storage tanks to wellhead

Technical assessment

Poor quality water may be used for the drilling and hydraulic fracturing operations. Failure of pumps and pipes could result in spillage of this water leading to groundwater contamination.

Mitigation measures

Specification of high quality pumps and pipes of suitable strength will minimise the risk of bursts. Pumps must not be operated until all pipeworks are securely attached.

Impact significance

It is anticipated that spillage of water will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.4.3 Intersection of aquifers

Preliminary Technical assessment

The gas exploration well may drill through the potential water bearing zones present at the well site. The well could therefore provide a pathway for groundwater loss.

Mitigation measures

Each well bore section will be lined with a steel casing, cemented in place. This process provides a barrier between the formations (that may include water bearing zones) and the well bore. Each well section would be lined with a steel casing, which in turn would be cemented in place. The casing and its accessories will be of such specifications that they can withhold downhole pressures and are resistant to the composition of the wellbore and formation fluids that they are exposed to. The casing integrity will be tested upon completion of the drilling to confirm that the casing can withstand the expected pressures and there are no leaks in the casing.

The cement around the casing holds the casing in place, but also is aimed to prevent communication (of pressure or fluids) around the outside of the casing between deeper and shallower formations, or even surface. The quality of the cement can be assessed through for example a Cement Bond Log. This log will

indicate whether there are possible communication paths through the cement. In case a so-called leak path would be detected, secondary operations may be undertaken in order to seal off the detected communication path.

During operations all annuli will be monitored to confirm no leaks develop over time. Also during production when the rig is no longer on site, it is common practice that the annuli are monitored at a regular basis. In case pressure or fluid levels are observed to increase, a full investigation will be carried out and if required production is halted or operations stopped (close in well). Once the investigation confirms the cause of the increased pressure or fluid levels, appropriate action will be taken to restore the required integrity.

Impact significance

It is anticipated that the well construction adopted will result in negligible groundwater impacts. Impacts of **low** significance are therefore expected.

6.4.4 Intersection of deep (saline) water bearing zones

Preliminary Technical assessment

The gas exploration well will drill to depths of up to 4 500m. A deep water bearing zone, most likely containing brackish or saline water, could be intersected. If the well was not adequately cased it could provide a pathway for saline water to rise to the surface and impacting on the shallower aquifer.

Mitigation measures

The same mitigation measures will be implemented as in Section 6.4.3.

Impact significance

It is anticipated that the well construction adopted will result in negligible groundwater impacts. Impacts of **low** significance are therefore expected.

6.4.5 Intersection of deep fractured zone

Preliminary Technical assessment

The gas exploration well will drill to depths of up to 4 500m. An unexpected fracture/fault zone could be intersected at depth. The well could therefore provide a pathway for groundwater loss to the fractured zone or and potentially saline water within the fracture rising to the surface and impacting on the shallower aquifer.

Mitigation measures

The same mitigation measures will be implemented as in Section 6.4.3.

Impact significance

It is anticipated that the site selection process and the well construction adopted will result in negligible groundwater impacts. Should there be doubt, the well will be abandoned and sealed, Impacts of **low** significance are therefore expected.

6.4.6 Failure of well casing or cement grout – groundwater inflow

Preliminary Technical assessment

Failure of the steel well casing and cement grout could lead to loss of groundwater via flow into the well.

Mitigation measures

The well construction involving steel casing and high pressure cement grouting is according to industry standards. The casing is pressure tested before installation to ensure that it is manufactured to standards. The grouting is verified using down logging. The aquifers will be sealed off and isolated from the well itself.

Impact significance

It is anticipated that the correct well construction and use of materials will provide protection against any failures. Negligible impacts to the groundwater system from the well are therefore anticipated. Impacts of **low** significance are therefore expected.

6.4.7 Failure of well casing or cement grout – groundwater contamination

Preliminary Technical assessment

Failure of the steel well casing and cement grout could lead to invasion of the aquifer by contaminated water, gas and hydraulic fracturing chemicals.

Mitigation measures

The well construction involving steel casing and high pressure cement grouting is according to industry standards. The casing is pressure tested before installation to ensure that it is manufactured to standards. The grouting is verify using down logging. The aquifers will be sealed off and isolated from the well itself.

Impact significance

It is anticipated that the correct well construction and use of materials will provide protection against any failures. Negligible impacts to the groundwater system from the well are therefore anticipated. Impacts of **low** significance are therefore expected.

6.4.8 Failure of steel casing to provide complete seal in the with hydraulic fracturing zone and leakage of gas and chemicals into the well

Preliminary Technical assessment

Failure of the steel well casing and cement grout due to stresses caused by installation depth and/or the hydraulic fracturing process could lead invasion of the well and the annulus by contaminated water, gas and hydraulic fracturing chemicals.

Mitigation measures

The well construction involving steel casing and high pressure cement grouting is according to proven industry standards. The integrity of the well casing is checked during the casing and hydraulic fracturing process. Should doubts exist concerning the well integrity the well will be abandoned and completely sealed with suitable cement grout

Impact significance

It is anticipated that the correct well construction and use of materials will provide protection against any failures. Negligible impacts to the groundwater system from the well are therefore anticipated. Impacts of **low** significance are therefore expected.

6.4.9 Hydraulic fracturing of the well leading to invasion of chemicals from the target shale horizon into the overlying aquifers via unknown fracture zones

Preliminary Technical assessment

Hydraulic fracturing of the shale is carried out under high pressure and is designed to crack the shale open to improve the permeability around the gas well. Concern has been expressed that the hydraulic fracturing process could lead to uncontrolled fracturing of the overlying strata. This could then provide a pathway for contamination of the groundwater via fractures newly created by the hydraulic fracturing process.

Mitigation measures

The hydraulic fracturing process is designed to fracture the shale in the target reservoir only. The gas exploration wells will be located away from fracture zones, dolerite dykes and other zones of potential weakness to minimise the risk of unexpected fracturing. The ground geophysical surveys are designed to identify such features and thus aid in positioning the well away from these lines of structural weakness.

The great depth at which the hydraulic fracturing will take place (1500 – 4500m below surface) provides substantial protection to the overlying groundwater aquifers due to the weight of the overlying rock mass which will counteract the hydraulic fracturing pressures.

Prior to the commencement of the drilling an EIA will first be undertaken. This detailed assessment of the selected site and surrounding area will involve monitoring of water levels and water quality over an extended

period of time. This monitoring will continue throughout the drilling and hydraulic fracturing process. Should any impact be detected hydraulic fracturing will cease.

Impact significance

It is anticipated that hydraulic fracturing will result in negligible impacts outside of the intended target shale zone. Impacts of **low** significance are therefore expected.

6.4.10 Larger volume of return water from the gas exploration well than expected

Preliminary Technical assessment

Up to 4 000m^3 of water will be used during the hydraulic fracturing process. This water will be pumped into the well and used to achieve the desired fracturing of the target shale horizon. It is anticipated that up to 30% of this water will be recovered. Recovered water is likely to be brackish or saline, will contain chemicals, gas and hydrocarbon products and will be stored on site close to the wellhead. Higher recoveries than anticipated could lead to the storage ponds overflowing and spillage occurring, which could in turn lead to an impact on the groundwater.

Mitigation measures

Storage facilities on site will be designed to accommodate the recovered water. Additional storage capacity will be provided to cope with unexpected volumes of water. The storage facilities will be robustly constructed to minimise the risk of leakage.

Impact significance

It is anticipated that the implementation of the mitigation measures will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected

6.4.11 Inflow of groundwater into the well lowering groundwater levels

Preliminary Technical assessment

Uncontrolled inflow of groundwater into the well could lead to a lowering of water levels and reduction of yield of surrounding water supply boreholes and loss of capacity of the nearby stock water and farm boreholes.

Mitigation measures

The well construction is designed to isolate the well from the groundwater aquifers. Gas exploration wells will not be positioned in proximity to water supply boreholes.

Impact significance

It is anticipated that the well construction will protect the groundwater resource and changes in groundwater levels and quality are not anticipated. Impacts will be negligible impacts and are judged to be of **low** significance.

6.4.12 Abstraction of groundwater resulting in lowering of water levels

Preliminary Technical assessment

Poorly managed abstraction of groundwater from the boreholes can lead to excessive lowering of the water table, failure of the borehole and possible lowering of the water level in water supply boreholes located within the area of influence of the wellsite borehole(s).

Mitigation measures

Ensure adherence to the management recommendations prepared as a result of the testing of the borehole(s). Monitoring of any nearby boreholes to detect any unexpected lowering of water levels or changes in water quality will be important.

Impact significance

It is anticipated that the abstraction from the boreholes will be in accordance with the management recommendations prepared. Accordingly impacts will be minor and are judged to be of **low** significance.

6.5 Technical Assessment: Decommissioning

Table 7 below summarises potential groundwater impacts directly related to decommissioning of a hypothetical gas exploration well, and provides a significance rating for each impact before and after mitigation.

Table 7: Preliminary Groundwater Technical Assessment Matrix for the proposed South Western Karoo Basin Gas Exploration Application Project – Decommissioning

PRELIMINARY ASSESSMENT OF POTENTIAL GROUNDWATER IMPACTS	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Leakage and spillage of contaminated water on site leading to contamination of groundwater	4	1	2	3	24	Low	2	1	1	2	8	Low
Leakage and spillage of stored chemicals leading to contamination of groundwater	4	1	2	3	24	Low	2	1	1	2	8	Low
Spillages and residues during and after site clean up	2	1	1	2	8	Low	2	1	1	2	8	Low
Leakage and spillage of contaminated water during transport to selected disposal site	2	1	2	2	10	Low	2	1	1	2	8	Low
Inadequate sealing of well resulting in poor sealing of gas and contaminated hydraulic fracturing water and subsequent invasion of the well and contamination to groundwater aquifer.	6	4	3	2	54	Moderate	2	4	2	1	14	Low
Inadequate sealing of water supply boreholes leading to aquifer contamination	6	4	2	2	24	Low	2	4	2	1	14	Low

6.5.1 Leakage and spillage of contaminated water

Preliminary Technical assessment

Poor quality water will be stored on site. Leakage and/or spillage of this water could result in groundwater contamination.

Mitigation measures

Ensure all water storage containers are located on the well pad. Water storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Remove stored/excess water as soon as practical.

Impact significance

It is anticipated that spillage of water will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.5.2 Leakage and spillage of stored chemicals

Preliminary Technical assessment

Drilling fluids and chemicals may be stored on site during decommissioning. Leakage and/or spillage of could result in groundwater contamination.

Mitigation measures

Ensure all storage containers are located on the well pad. The storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Personnel to be trained to conduct correct and careful handling of drilling fluids and chemicals. Suitable intervention and cleanup plan must be in place and clean up facilities available on stand by. Remove stored/excess chemicals as soon as practical.

Impact significance

It is anticipated that spillages will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.5.3 Spillages and residues during and after site clean up

Preliminary Technical assessment

Storage containers and return water dam will need to be removed from the site to minimise risk of long pollution of groundwater.

Mitigation measures

Correct handling and storage of the water and chemical storage facilities during operation. Careful removal of facilities from site once empty. Clean up of any residues present on the well pad.

Impact significance

It is anticipated that clean up will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.5.4 Leakage and spillage of contaminated water during transport to selected disposal site

Preliminary Impact assessment

Contaminated water and chemicals ill need to be removed from site during decommissioning. Leakage and/or spillage while being transported could result in groundwater contamination.

Mitigation measures

Tankers must be mechanically sound, all pumps and pipes delivering water from the storage tanks must be in sound condition, tanker drivers to be experienced and trained in driving hazardous loads. Tankers must be marked with the appropriate signage. Should an accident or spill occur authorities to be alerted and clean up operations implemented.

Impact significance

It is anticipated that spillages will result in negligible impacts, and will be restricted to the site only. Impacts of **low** significance are therefore expected.

6.5.5 Inadequate sealing of well resulting in poor sealing of gas and hydraulic fracturing water resulting in impacts on aquifers

Preliminary Technical assessment

The well provides a potential pathway from the gas reservoir to surface inadequate sealing of the well has potential to allow gas and/or any remaining water (from hydraulic fracturing) to impact on groundwater near the surface.

Mitigation measures

If the well is abandoned it is to be sealed by filling with cement grout under pressure. Ensure correct application of pressure grouting techniques, including maintaining records of the volume of cement used compared to volume of the well.

Impact significance

It is anticipated sealing of the wells will result in negligible impacts to the groundwater regime. Impacts of **low** significance are therefore expected.

6.5.5.1 Inadequate sealing of water supply boreholes leading to impacts on aquifers impact

Preliminary Technical assessment

The water supply borehole provides a pathway from surface into the aquifer for poor quality water to enter the aquifer. The borehole also provides a pathway for brackish and/or saline groundwater targeted at depth to impact the overlying freshwater aquifer, should there be an large positive hydraulic head acting on the deeper aquifer.

If potable quality groundwater has been used, the borehole can be incorporated into the long term monitoring system, or handed over to the landowner.

Mitigation measures

If the borehole is to be abandoned then it is to be backfilled and sealed according to industry standards. This could involve pressure grouting the hole closed.

Impact significance

It is anticipated sealing of the wells, use for monitoring or handing over to the landowner will result in negligible impacts to the groundwater regime. Impacts of **low** significance are therefore expected.

6.5.6 Assumptions and knowledge gaps / limitations

This preliminary assessment of potential impacts to the groundwater regime has been prepared without detailed knowledge of the actual drilling site. It is therefore indicative at this stage.

A detailed assessment of potential impacts to the groundwater aquifers will be undertaken as part of the EIA, once the site selection has been completed.

7.0 MITIGATION AND MANAGEMENT MEASURES

7.1 Site preparation

The following mitigation measures have been identified for site preparation (Table 8).

7.2 Exploration drilling and hydraulic fracturing

The following mitigation measures have been identified for the exploration drilling and hydraulic fracturing activities of the proposed project (Table 9).

7.3 Decommissioning

The following mitigation measures have been identified for the decommissioning of the proposed project (Table 10).

8.0 RECOMMENDATIONS FOR THE DETAILED TECHNICAL ASSESSMENT

The preliminary groundwater technical assessment described in section 6 above is based upon a hypothetical or generic site. The preliminary assessment does not replace the detailed studies that are required for the future EIA. A detailed groundwater technical assessment of the selected gas exploration drill site must be undertaken once the drill site has been selected following specified siting criteria and before any drilling can actually commence.

8.1 Site selection criteria to consider in the detailed technical assessment

The selection of the sites for the drilling of the gas exploration wells will consider the following criteria pertinent to mitigating potential impacts on the groundwater system.

- Proximity to existing water supply boreholes;
- Groundwater levels and flow directions in the selected area;
- Groundwater quality;
- Groundwater occurrence and lithologies comprising aquifer in the area;
- Depth of groundwater occurrence in the area. Proximity of dolerite dyke and sill intrusions. Drilling sites will need to be a sufficient distance from dolerite dykes and sill contact zones to minimise any risk of impacting on associated aquifers;
- Proximity and impacts associated with fault zones. Sites will not be selected close to surface drainage.

The site selection process will be robust and will involve study of imagery, existing data and the running of a ground Magneto-Tellurics geophysical survey. This geophysical technique has the ability to penetrate up to a 10km depth and is a powerful tool to aid in site selection.

8.2 Key questions that will need to be answered in the EIA

The following key questions will need to be answered in the EIA undertaken in the next phase of the project:

- Where are the groundwater users in close proximity to the site?
- Are there any groundwater springs in close proximity to the site?
- What is the quality of the groundwater used near the site|?
- What is the quality of the water in the springs near the site?
- What is the baseline hydrogeological regime at the site?
- What will be the impact on groundwater levels and quality due to the exploration project?
- What mitigation measures will be implemented to ensure impacts are at an acceptable level?

Table 8: Environmental Management Plan for Groundwater Impact Mitigation for proposed South Western Karoo Basin Gas Exploration Application Project – site preparation

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Construction of the well pad leading to reduction in groundwater recharge				
	Project activity:	Levelling and compacting soil to construct well pad 100m x 100m	-	-
	Impact:	Reduction in permeability	-	-
	Mitigation measure(s):	Direct clean storm water to soakaways	As appropriate, throughout construction, operation and decommisssioning	Contractor
Leakage of stored (poor quality) water on site leading to deterioration of groundwater quality at the site				
	Project activity:	Storage of (poor quality) water for future drilling operations	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Ensure all water storage containers are located on the well pad. Water storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Clean up spillages at once	As appropriate, throughout construction	Contractor/ operator
Leakage of stored drilling fluids and chemicals leading to deterioration of groundwater quality at the site				
	Project activity:	Storage of chemicals for use in future drilling operations	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Ensure all chemical storage containers are located on the well pad. Chemical storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Clean up spillages at once	As appropriate, throughout construction	Contractor
Geophysical data acquisition using Magneto-Tellurics surveying				
	Project activity:	Running of ground geophysical surveys to assist in site selection	-	-
	Impact:	Non intrusive, no risk of groundwater impact	-	-
	Mitigation measure(s):	None required	-	-
Wellfield development to obtain a groundwater supply				
	Project activity:	Development of a groundwater supply borehole(s)	-	-
	Impact:	Drawdown of water levels in nearby boreholes. Mixing of deeper brackish and/or saline with overlying potable groundwater	-	-
	Mitigation measure(s):	Undertake a through survey of the area to select boreholes in areas away from existing water supply boreholes. This will include a desk study, hydrocensus, water quality assessment and non	As appropriate, throughout construction	Hydrogeologist/ Drilling and testing Contractor

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
		intrusive geophysical survey. Boreholes must be sited an adequate distance from existing water supply boreholes. Drilling of water supply boreholes must follow industry standards and be undertaken by an experience water well driller using the correct equipment. Drilling will be undertaken using the air percussion drilling technique, boreholes will be cased using new steel plain and slotted casing as required. If the target aquifer is a deep brackish or saline water body located below the fresh water aquifer, this shallow aquifer must be correctly sealed off with plain casing grouted into place to isolate the potable water body. The borehole completion must include a sanitary seal/cement grout to prevent contamination of the groundwater aquifer by surface water inflow via the borehole annulus. The holes must be correctly capped to prevent direct access into the borehole of contaminated surface water. The boreholes must be test pumped to confirm the yield and prepare management recommendations for the responsible use of the water resource		

Table 9: Environmental Management Plan for Groundwater Impact Mitigation for proposed South Western Karoo Basin Gas Exploration Application Project – exploration drilling and hydraulic fracturing

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Storage tanks leak/collapse/burst leading contamination of aquifer				
	Project activity:	Storage of poor quality water for drilling and hydraulic fracturing operations	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Ensure all water storage containers are located on the well pad. Water storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Clean up spillages at once	As appropriate, throughout operation	Drilling & Hydraulic fracturing Contractor. Well site manager
Leakage of stored drilling fluids and chemicals leading to deterioration of groundwater quality at the site				
	Project activity:	Storage of drilling fluids and chemicals for drilling and hydraulic fracturing operations	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Ensure all chemical storage containers are located on the well pad. Chemical storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Clean up spillages at once. Personnel to be trained in correct handling	As appropriate, throughout operation	Drilling & Hydraulic fracturing Contractor. Well site manager
Pumps/pipes to/from storage tanks to wellhead fail resulting in spillage				
	Project activity:	Transfer/pumping of drilling and hydraulic fracturing chemicals from storage tanks to the well	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Specification of high quality pumps and pipes of suitable strength will minimise the risk of bursts. Ensure all pumps and pipe works are located on the well pad. Area to be bunded to contain any spillage. Clean up spillages at once. Pumps must not be operated until all pipeworks are securely attached	As appropriate, throughout drilling and hydraulic fracturing operations	Drilling & Hydraulic fracturing Contractor, Well site manager
Intersection of aquifers				
	Project activity:	Drilling of the gas exploration well	-	-
	Impact:	Drilling through the aquifer horizons in upper 50 – 150m of the well	-	-
	Mitigation measure(s):	Select site in area of minimal groundwater occurrence. Securely case with plain steel casing and grouted in place using high pressure cement grouting techniques. This will seal and isolate the well from the groundwater horizons hence no flow of groundwater into the well, or movement of contaminated hydrofracturing water and/or chemicals could enter the aquifer from the well.	Siting process and during initial portion of drilling	Shell siting team. Drilling Contractor

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Intersection of deep saline aquifers				
	Project activity:	Drilling of gas exploration well to up to 4 500m	-	-
	Impact:	Intersection of deep aquifer	-	-
	Mitigation measure(s):	Select site in area of minimal groundwater occurrence. Securely case with plain steel casing and grouted in place using high pressure cement grouting techniques. This will seal and isolate the well from deep groundwater horizons hence no flow of groundwater into the well can occur.	Siting process and during drilling	Shell siting team. Drilling Contractor
Intersection of significant fracture zone				
	Project activity:	Drilling of gas exploration well to up to 4 500m	-	-
	Impact:	Intersection of unexpected fracture/fault zone	-	-
	Mitigation measure(s):	The site selection process will ensure that the gas exploration well is drilled in a position where structures are unlikely to be encountered. Securely case with plain steel casing and grouted in place using high pressure cement grouting techniques to seal and isolate the well from deep structures. Depending upon the magnitude of the fracture zone encountered, the well could be abandoned since gas could have escaped.	Siting process and during drilling	Shell siting team. Drilling Contractor. Shell drilling supervisor
Failure of steel well casing and cement grout to provide complete seal with aquifer and leaking of groundwater into the annulus				
	Project activity:	Drilling of gas exploration well to up to 4 500m and hydraulic fracturing	-	-
	Impact:	Loss of protection to groundwater resources	-	-
	Mitigation measure(s):	The well construction involving steel casing and high pressure cement grouting is according to industry standards. The aquifers will be sealed off and isolated from the well itself.	During drilling and hydraulic fracturing	Drilling & Hydraulic fracturing Contractor
Failure of steel casing to provide complete seal with hydraulic fracturing zone and leakage of gas and chemicals into the well annulus and subsequently into the overlying aquifers				
	Project activity:	Hydraulic fracturing of well	-	-
	Impact:	Loss of integrity of well allowing gas and contaminated water to enter annulus	-	-
	Mitigation measure(s):	The well construction involving steel casing and high pressure cement grouting is according to proven industry standards. The integrity of the well casing is checked during the casing and hydraulic fracturing process. Should doubts exist concerning the well integrity the well will be abandoned and completely sealed with suitable cement grout	During drilling and hydraulic fracturing	Drilling & Hydraulic fracturing Contractor

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Hydraulic fracturing of the well leading to invasion of chemicals from the target shale horizon into the overlying aquifers via unknown fracture zones				
	Project activity:	Hydraulic fracturing of well	-	-
	Impact:	Concern has been expressed that the hydraulic fracturing process could lead to uncontrolled fracturing of the overlying strata. This could then and provide a pathway for contamination of the groundwater via fractures newly created by the hydraulic fracturing process.	-	-
	Mitigation measure(s):	The hydraulic fracturing process is designed to fracture the shale in the target reservoir only. The gas exploration wells will be located away from fracture zones, dolerite dykes and other zones of potential weakness to minimise the risk of unexpected fracturing. The ground geophysical surveys are designed to identify such features and thus aid in positioning the well away from these lines of structural weakness. The great depth at which the hydraulic fracturing will take place (1500 – 4500m below surface) provides substantial protection to the overlying groundwater aquifers due to the weight of the overlying rock mass which will counteract the hydraulic fracturing pressures. Prior to the commencement of the drilling an EIA will first be undertaken. This detailed assessment of the selected site and surrounding area will involve monitoring of water levels and water quality over an extended period of time. This monitoring will continue throughout the drilling and hydraulic fracturing process. Should any impact be detected hydraulic fracturing will cease.	Site selection process before drilling Hydraulic fracturing operations Monitoring	Shell geophysical team Drilling & Hydraulic fracturing Contractor Shell well site supervisor Monitoring team
Larger volume of return water from the gas exploration well than expected resulting in the return water storage dam filling and overflowing and/or spillage of saline/brackish return water from the well causing contamination of the underlying groundwater				
	Project activity:	Hydraulic fracturing with up to 4 000m^3 of water and gas testing.	-	-
	Impact:	Larger than anticipated return of contaminated water leading to containment problem on surface and potential groundwater contamination	-	-
	Mitigation measure(s):	Storage facilities on site will be designed to accommodate the recovered water. Additional storage capacity will be provided to cope with unexpected volumes of water. The storage facilities will be robustly constructed to minimise the risk of leakage.	Hydraulic fracturing and gas testing	Hydraulic fracturing Contractor Shell well site supervisor and gas testing team

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Inflow of groundwater into the well causing a lowering of water levels and loss of capacity of nearby stock watering/farm boreholes				
	Project activity:	Drilling, hydraulic fracturing and testing of gas exploration well	-	-
	Impact:	Uncontrolled inflow of groundwater into the well could lead to a lowering of water levels and reduction of yield of surrounding water supply boreholes	-	-
	Mitigation measure(s):	The well construction is designed to isolate the well from the groundwater aquifers. Gas exploration wells will not be positioned in proximity to water supply boreholes. Monitoring as required.	During drilling, hydraulic fracturing and gas testing	Drilling and hydraulic fracturing Contractor Shell well site supervisor and gas testing team Monitoring team
Abstraction of groundwater for water supply to the drilling and hydraulic fracturing operations				
	Project activity:	Pumping from the water supply borehole(s) to supply drilling and hydraulic fracturing water	-	-
	Impact:	Poorly managed abstraction of groundwater from the boreholes can lead to excessive lowering of the water table, failure of the borehole, and possible lowering of the water level in water supply boreholes located within the area of influence of the wellsite borehole(s).	-	-
	Mitigation measure(s):	Ensure adherence to the management recommendations prepared as a result of the testing of the borehole(s). Monitor nearby boreholes to detect any unexpected lowering of water levels or changes in water quality, including the monitoring holes drilled as part of the detailed EIA.	During drilling, hydraulic fracturing and gas testing	Shell well site supervisor/ drilling, hydraulic fracturing and gas test contractor Monitoring team

Table 10: Environmental Management Plan for Groundwater Impact Mitigation for proposed South Western Karoo Basin Gas Exploration Application Project – Decommissioning

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Leakage and spillage of contaminated water on site leading to contamination of groundwater				
	Project activity:	Storage of excess water		-
	Impact:	Contamination of groundwater		-
	Mitigation measure(s):	Ensure all water storage containers are located on the well pad. Water storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Remove stored/excess water as soon as practical.	As appropriate, throughout decommissioning	Contractor Well site supervisor
Leakage and spillage of stored chemicals leading to contamination of groundwater				
	Project activity:	Storage of excess chemicals	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Ensure all chemical storage containers are located on the well pad. Chemical storage containers must be robust and not overfilled. Area to be bunded to contain any spillage. Clean up spillages at once. Personnel to be trained in correct handling. Remove stored/excess chemicals as soon as practical.	As appropriate, throughout decommissioning	Contractor Well site supervisor
Spillages and residues during and after site clean up				
	Project activity:	Removal of storage containers, dismantling of reservoirs		-
	Impact:	Contamination of groundwater		-
	Mitigation measure(s):	Correct handling and storage of the water and chemical storage facilities during operation. Careful removal of facilities from site once empty. Clean up of any residues present on the well pad	As appropriate, throughout decommissioning	Contractor Well site supervisor
Leakage and spillage of contaminated water during transport to selected disposal site				
	Project activity:	Removal of contaminated water and chemicals from site	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Tankers must be mechanically sound, all pumps and pipes delivering water from the storage tanks must be in sound condition, tanker drivers to be experienced and trained in driving hazardous loads. Tankers must be marked with the appropriate signage. Should an accident or spill occur authorities to be alerted and clean up operations implemented	As appropriate, throughout decommissioning	Transport Contractor

Environmental Management Plan for Groundwater Protection			Timeline and frequency	Responsible party
Inadequate sealing of well resulting in poor sealing of gas and contaminated hydraulic fracturing water and subsequent invasion of the well and contamination to groundwater aquifers				
	Project activity:	Sealing of gas well with cement	-	-
	Impact:	Contamination of groundwater	-	-
	Mitigation measure(s):	Ensure correct application of pressure grouting techniques, including maintaining records of the volume of cement used compared to volume of the well.	As appropriate, throughout decommissioning	Grouting Contractor Well site supervisor Monitoring team
Inadequate sealing of water supply boreholes leading to aquifer contamination				
	Project activity:	Abandonment of Borehole and sealing	-	-
	Impact:	The water supply borehole provides a pathway from surface into the aquifer for poor quality water to enter the aquifer. The borehole also provides a pathway for brackish and/or saline groundwater targeted at depth to contaminate the overlying freshwater aquifer, should there be an positive hydraulic head acting on the deeper aquifer.	-	-
	Mitigation measure(s):	If potable quality groundwater has been used, the borehole can be incorporated into the long term monitoring system, or handed over to the landowner. If the borehole is to be abandoned then it is to be backfilled and sealed according to industry standards. This could involve pressure grouting the hole closed.	As appropriate, throughout decommissioning	Grouting Contractor Well site supervisor Monitoring team

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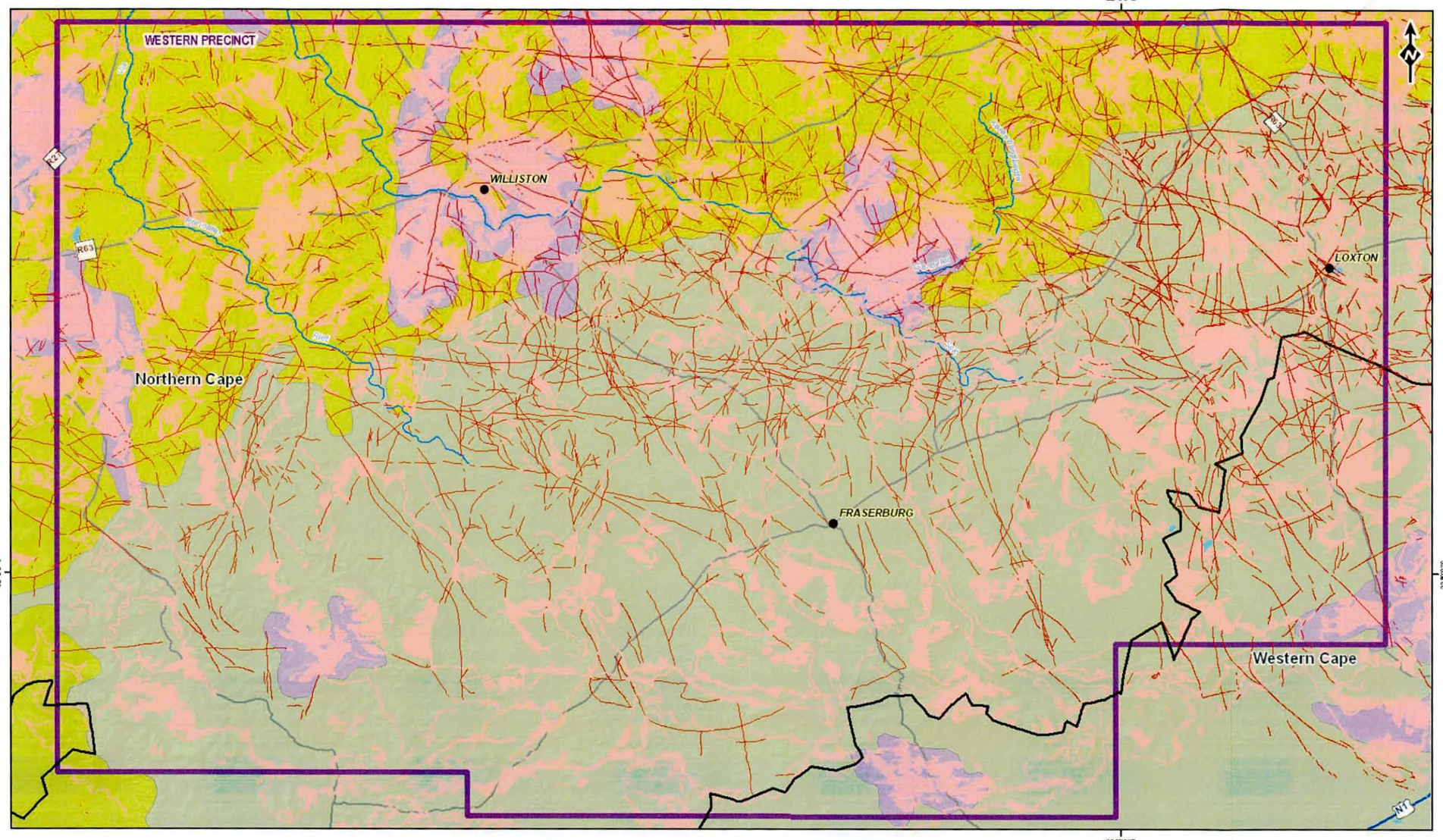
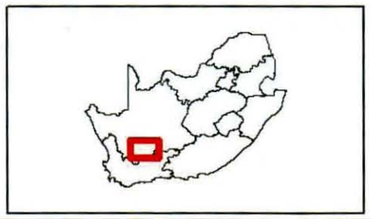
Reg. No. 2002/007104/07
Directors: FR Sutherland, AM van Niekerk, SAP Brown, L Greyling

ATTACHMENT A

MAPS - WESTERN PRECINCT

Map 1: Regional Geology
Map 2: Regional Hydrogeology
Map 3: Borehole Drilling Depths
Map 4: Depth to Water Level
Map 5: Water Quality (EC)
Map 6: Registered Water Use





LEGEND

- Towns
- Major dam
- 3122_dolorite_dyke
- Province boundary
- Exploration application areas
- National route
- Main road
- River
- Dolerite dyke

Simplified geology

- Drakensberg
- Adelaide
- Ecca
- Dolerite sill

RESOURCES/NOTES

Compiled from
Simplified Geology (1:1,000,000) - DWA
Published Geological Maps (1:250,000)
Council of Geoscience

0 5 10 20 30 40
Kilometres

REFERENCE

PROJECTION GCS Hartebeesthoek 1994

PROJECT

SHELL KAROO BASIN EXPLORATION

TITLE

MAP W1

REGIONAL GEOLOGY - WESTERN PRECINCT

Golder Associates
Johannesburg, South Africa

GIS	IDT	2011/02/23	PROJECT No. 12800	
CHECK	FW	2011/02/23	SCALE 1:700,000	
REVIEW	GH	2011/02/23	A3	REV 0

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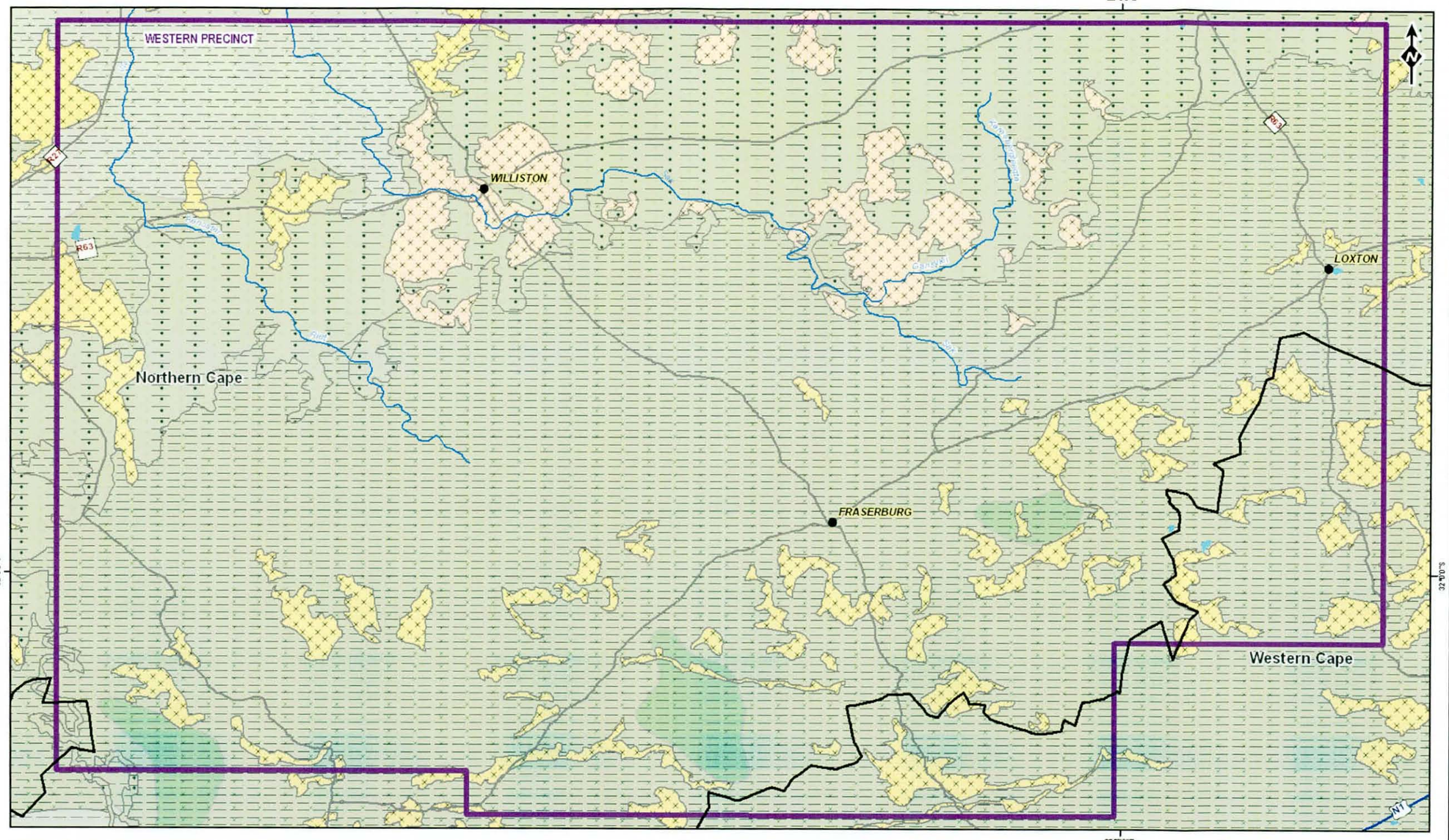

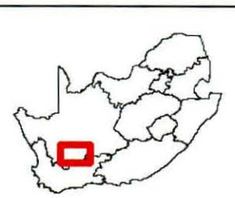

LEGEND

- Town
- Provincial boundary
- Exploration application area
- Major dam
- River
- National route
- Main road

Simplified Lithology

- Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
- Argillaceous and arenaceous rocks (approximately equal proportions)
- Mafic/Ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
- Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
- Argillaceous and arenaceous rocks (approximately equal proportions)

Groundwater Occurrence - Borehole Yield

- Fractured 0.1 - 0.5 *Vs*
- Fractured 0.5 - 2.0 *Vs*
- Fractured 2.0 - 5.0 *Vs*
- Intergranular and Fractured 0.1 - 0.5 *Vs*
- Intergranular and Fractured 0.5 - 2.0 *Vs*

RESOURCE NOTES

Compiled from
Hydrogeological Map Series
1:500,000 Scale
DWA 1996 - 2003

0 5 10 20 30 40
Kilometres

REFERENCE

PROJECTION GCS Hartebeesthoek 1994

PROJECT
SHELL KAROO BASIN EXPLORATION

TITLE
MAP W2
REGIONAL HYDROGEOLOGY - WESTERN PRECINCT

Golder Associates
Johannesburg, South Africa

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REVIEW	GH	2011/02/10	A3	REV 0

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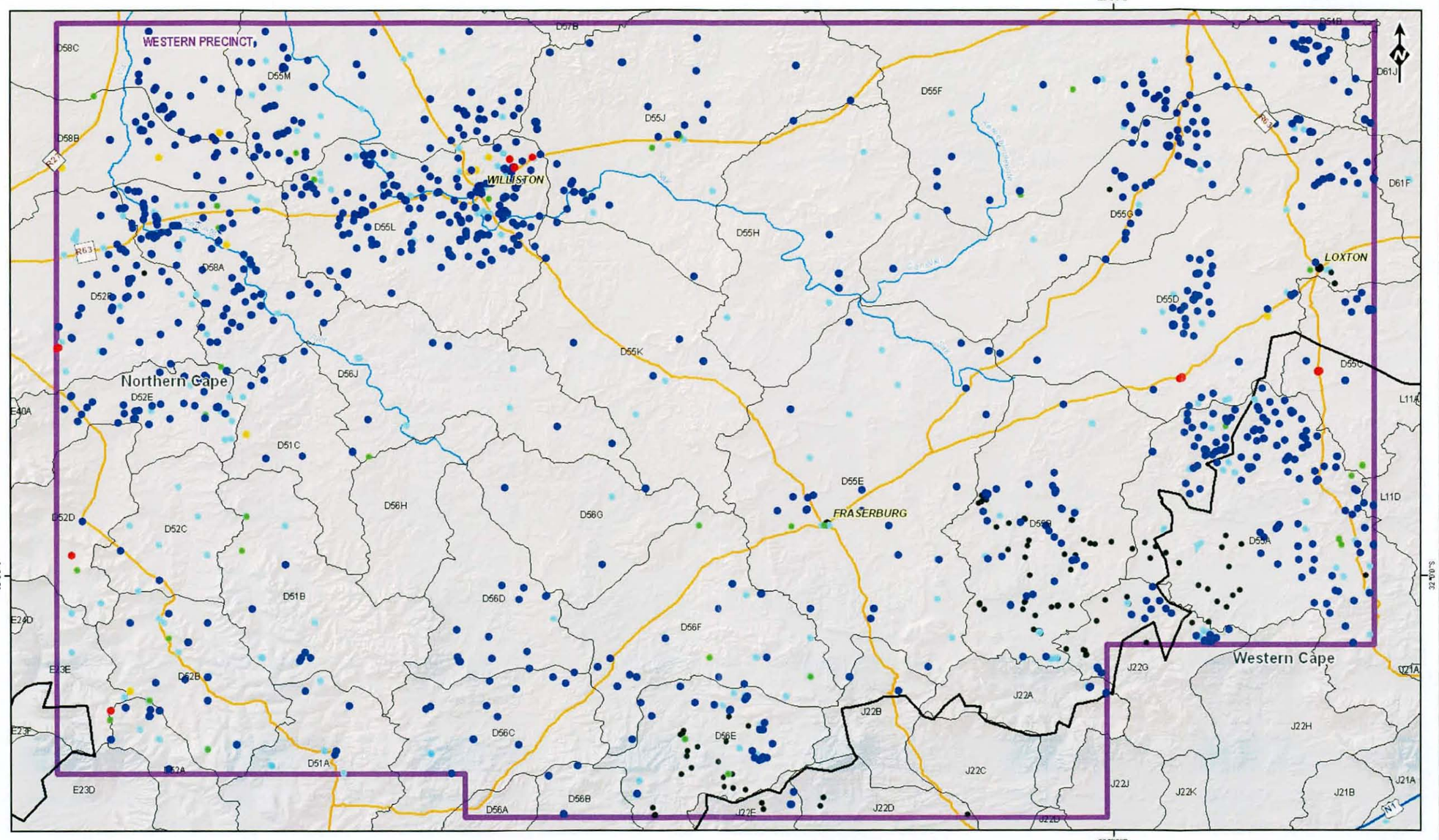

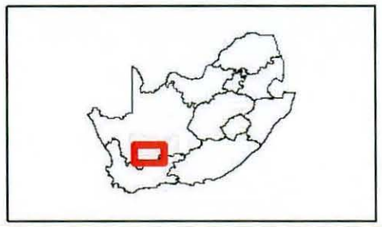

LEGEND

- Town
- Provincial boundary
- Exploration application area
- Major dam
- River
- National route
- Main road
- Quaternary catchments

Borehole Drilling Depths

Total Records = 1896

- >0 - 50 (1298)
- 50 - 100 (472)
- 100 - 150 (78)
- 150 - 200 (26)
- 200 - 300 (22)
- No Data

RESOURCE NOTES

Borehole Data Compiled from NGDB Data (DWA - 2008)

0 5 10 20 30 40
Kilometres

REFERENCE

PROJECTION GCS Hartebeesthoek 1994

PROJECT

SHELL KAROO BASIN EXPLORATION

TITLE

MAP W3

BOREHOLE DRILLING DEPTHS - WESTERN PRECINCT

Golder Associates
Johannesburg, South Africa

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REVIEW	GH	2011/02/11	A3	REV 0

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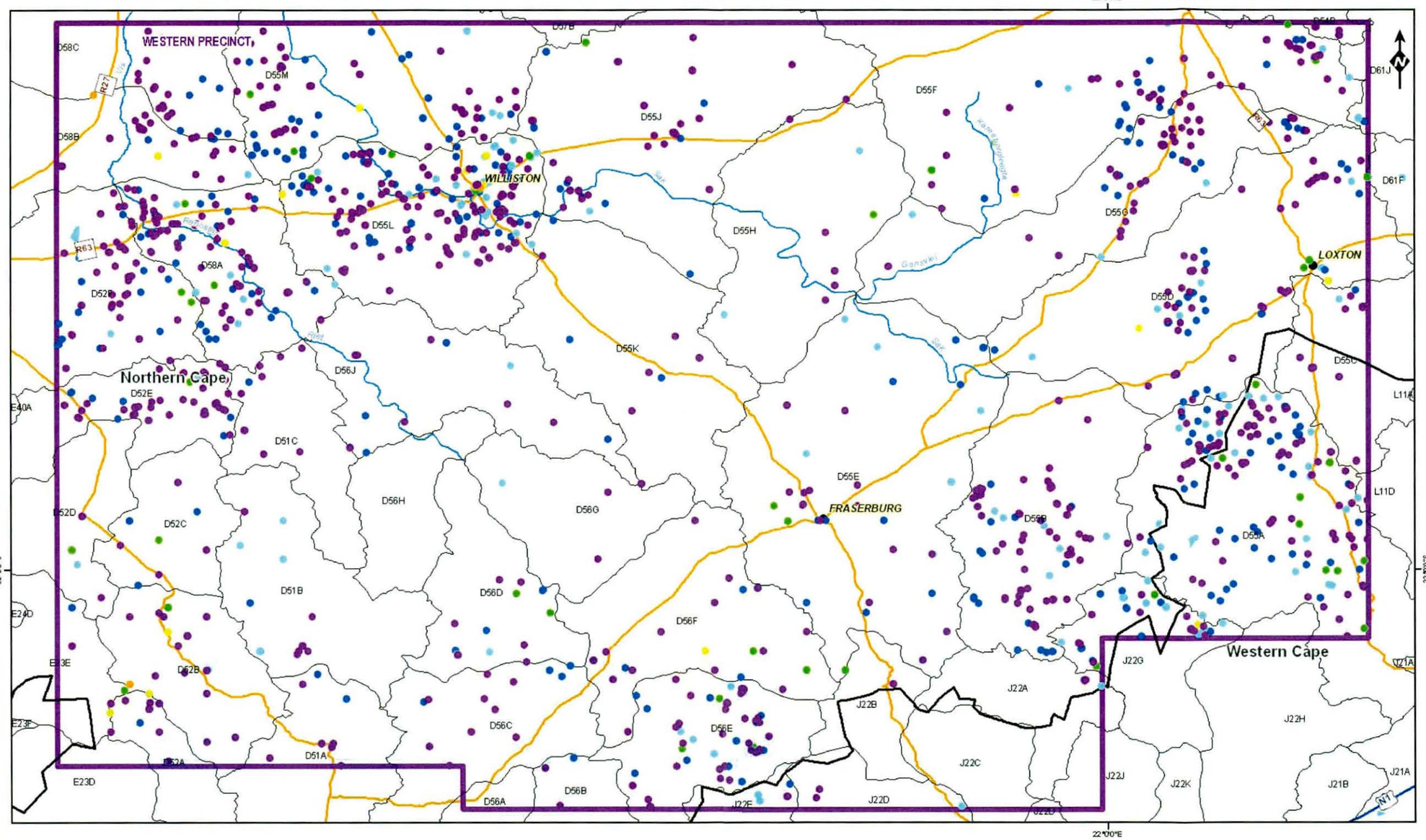

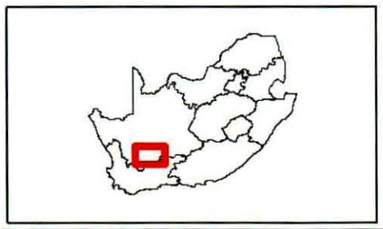

LEGEND

- Town
- Provincial boundary
- Exploration application area
- Major dam
- River
- National route
- Main road
- Quaternary catchments

Groundwater Level (mbgl)

Total Records 2014

- 0 - 10 (1098)
- 10 - 20 (564)
- 20 - 30 (203)
- 30 - 50 (108)
- 50 - 75 (33)
- 75 - 100 (8)
- >100 (0)

RESOURCE NOTES

Borehole Data Compiled from NGDB Data (DWA - 2008)

0 5 10 20 30 40
Kilometres

REFERENCE

PROJECTION GCS Hartebeesthoek 1994

PROJECT

SHELL KAROO BASIN EXPLORATION

TITLE

MAP W4

DEPTH TO WATER LEVEL - WESTERN PRECINCT

Golder Associates
Johannesburg, South Africa

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CHECK	FW	2011/02/15	SCALE 1:700,000	
REVIEW	GH	2011/02/15	A3	REV 0

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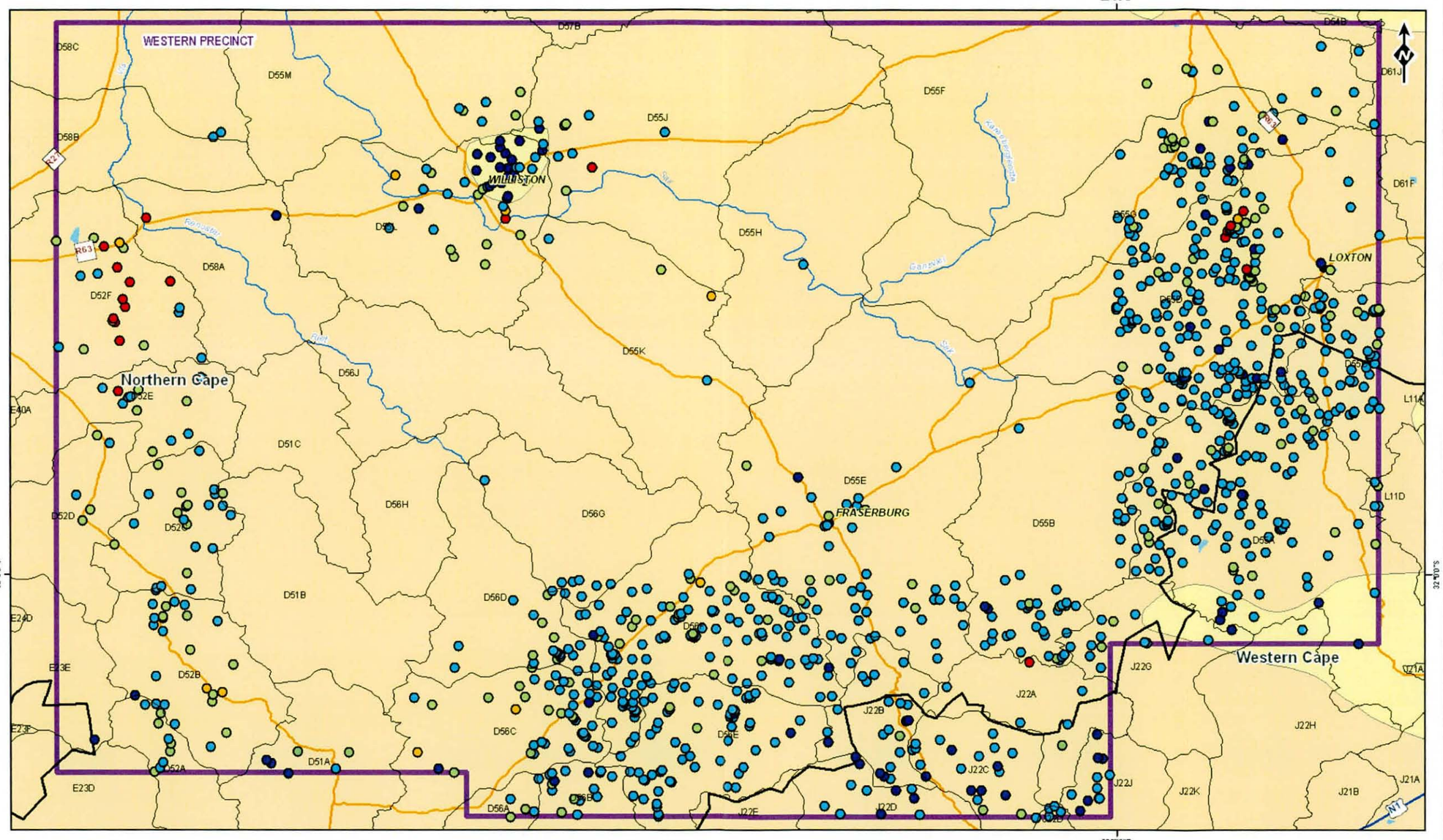

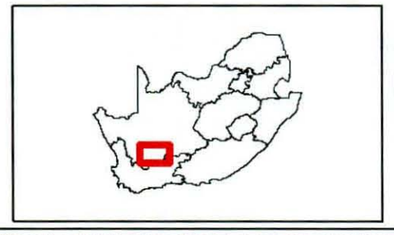

LEGEND

- Town
- Provincial boundary
- Exploration application area
- Major dam
- River
- National route
- Main road
- Quaternary catchments

Water Quality : Records = 1276

Class: Electrical Conductivity

- Class 0: < 70 (93)
- Class 1: 70 - 150 (940)
- Class 2: 150 - 370 (205)
- Class 3: 371 - 520 (15)
- Class4: > 520 (23)

Electrical Conductivity Zones

Source : Hydrogeological Map Series

- 0 - 70 mS/m
- 70 - 300 mS/m
- 300 - 1000 mS/m

RESOURCE NOTES

Borehole Data Compiled from WQMS Data (DWA - 2008)

0 5 10 20 30 40
Kilometres

REFERENCE

PROJECTION GCS Hartebeesthoek 1994

PROJECT

SHELL KAROO BASIN EXPLORATION

TITLE

MAP W5

WATER QUALITY (EC) - WESTERN PRECINCT

Golder Associates
Johannesburg, South Africa

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REVIEW	GH	2011/02/14	A3	REV 0

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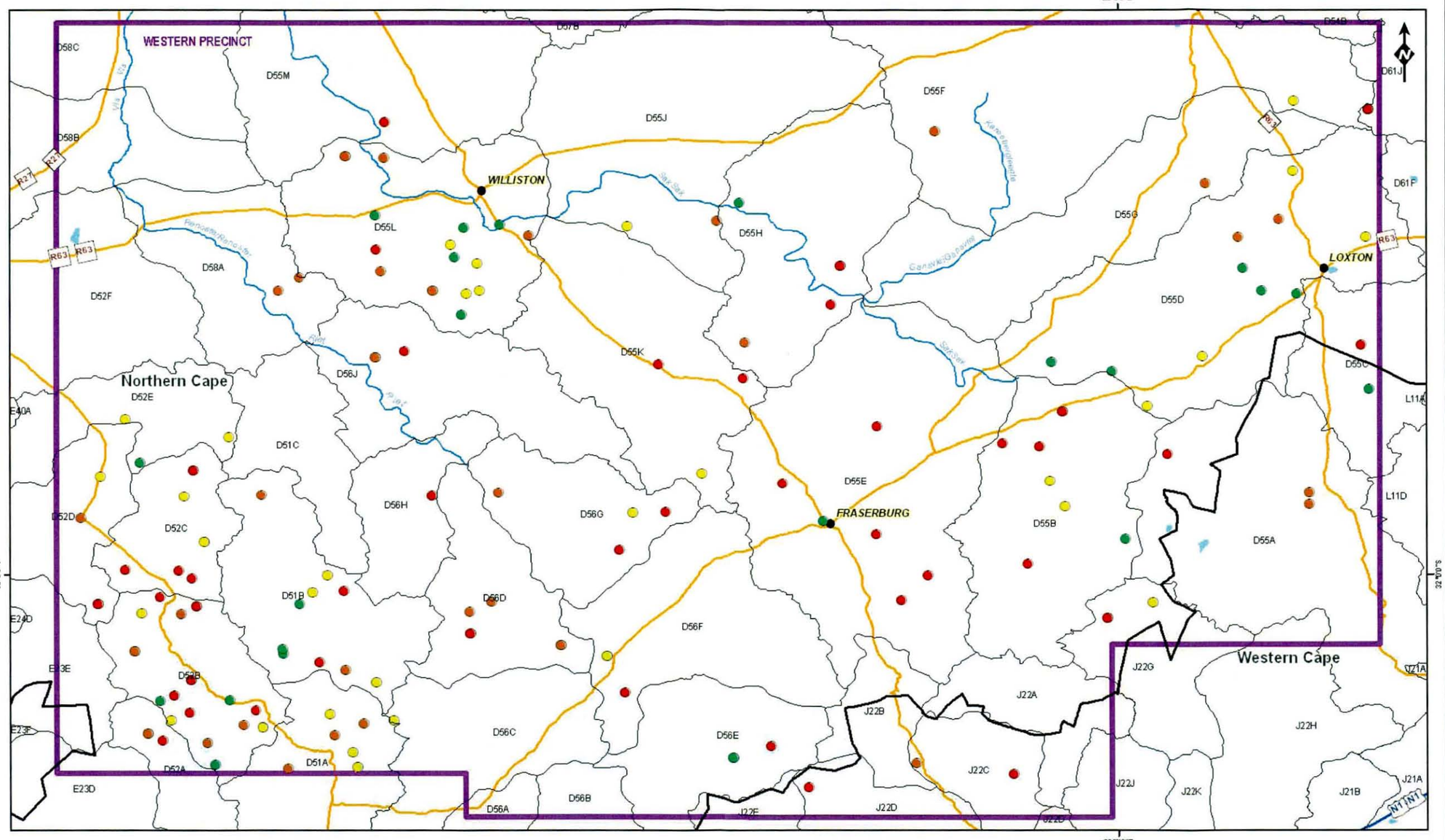

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ATTACHMENT B

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