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Please note reference books, field guides and guidelines not necessarily referenced in the text but used during fieldwork and in the compilation and structure of the report have also been included in this reference list.

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APPENDIX A

Vegetation Biomes

February 2011
Report No. 1280012800-10444-21

Golder Associates

Thicket

The "Thicket Biome" was only recently recognised in the scientific literature, although it was referred to in Low and Rebelo (1998) as a biome. Mucina and Rutherford (2006) formally named the various Thickets and indicated it as a biome. The vegetation which replaces forest - where a degree of fire protection is still evident, but rainfall is too low - did not fit within the "Forest" type as it does not have the required height nor the many strata below the canopy. Nor is it a "Savanna" type, in that it does not have a conspicuous grassy ground layer.

Subtropical thicket is a closed shrubland to low forest dominated by evergreen, sclerophyllous or succulent trees, shrubs and vines, many of which have stem spines. It is often almost impenetrable, is generally not divided into strata, and has little herbaceous cover. Because the vegetation types within the "Thicket Biome" share floristic components with many other phytochoria and lie within almost all the formal biomes, Thicket types have been referred to as "transitional thicket". Thicket types contain few endemics, most of which are succulents of Karoo origin (e.g. *Crassula* spp. and *Delosperma* spp.).

Grasslands

The Grassland Biome is found chiefly on the high central plateau of South Africa, and the inland areas of KwaZulu-Natal and the Eastern Cape. The topography is mainly flat and rolling, but includes the escarpment itself. Altitude varies from near sea level to 2 850 m above sea level.

Grasslands (also known locally as Grassveld) are dominated by a single layer of grasses. The amount of cover depends on rainfall and the degree of grazing. Trees are absent, except in a few localized habitats. Geophytes (bulbs) are often abundant. Frosts, fire and grazing maintain the grass dominance and prevent the establishment of trees.

There are two categories of grass plants: sweet grasses have lower fibre content, maintain their nutrients in the leaves in winter and are therefore palatable to stock. Sour grasses have higher fibre content and tend to withdraw their nutrients from the leaves during winter so that they are unpalatable to stock. At higher rainfall and on more acidic soils, sour grasses prevail, with 625 mm per year taken as the level at which unpalatable grasses predominate. C4 grasses dominate throughout the biome, except at the highest altitudes where C3 grasses become prominent.

Grass plants tolerate grazing, fire, and even mowing, well: most produce new stems readily, using a wide variety of strategies. Overgrazing tends to increase the proportion of pioneer, creeping and annual grasses, and it is in the transition zones between sweet and sour grass dominance that careful management is required to maintain the abundance of sweet grasses. The Grassland Biome is the mainstay of dairy, beef and wool production in South Africa. Pastures may be augmented in wetter areas by the addition of legumes and sweet grasses.

The Grassland Biome is the cornerstone of the maize crop, and many grassland types have been converted to this crop. Sorghum, wheat and sunflowers are also farmed on a smaller scale.

Urbanization is a major additional influence on the loss of natural areas - the Witwatersrand is centred in this biome. The Grassland Biome is considered to have an extremely high biodiversity, second only to the Fynbos Biome. Rare plants are often found in the grasslands, especially in the escarpment area. These rare species are often endangered, comprising mainly endemic geophytes or dicotyledonous herbaceous plants. Very few grasses are rare or endangered.

The most noteworthy species with a wide distribution is, *Themeda triandra*, more commonly referred to as 'rooigras'. The ungulate fauna (*hoofed animals*) of the grassland areas included vast herds of Blesbok (*Damaliscus dorcas phillipsi*), Black Wildebeest (*Connochaetes gnou*) and the Springbok (*Antidorcas marsupialis*). A rich variety of birds are found in the grasslands, including the Blue Crane (*Anthropoides paradiseus*), Black Korhaan (*Eupodotis afra*) and Helmeted Guineafowl (*Numida meleagris*).

Nama-Karoo

The Nama Karoo Biome occurs on the central plateau of the western half of South Africa, at altitudes between 500 and 2000m, with most of the biome failing between 1000 and 1400m. It is the second-largest biome in the region.

The geology underlying the biome is varied, as the distribution of this biome is determined primarily by rainfall. The rain falls in summer, and varies between 100 and 520mm per year. This also determines the predominant soil type - over 80% of the area is covered by a lime-rich, weakly developed soil over rock. Although less than 5% of rain reaches the rivers, the high erodibility of soils poses a major problem where overgrazing occurs.

The dominant vegetation is a grassy, dwarf shrubland. Grasses tend to be more common in depressions and on sandy soils, and less abundant on clayey soils. Grazing rapidly increases the relative abundance of shrubs. Most of the grasses are of the C4 type and, like the shrubs, are deciduous in response to rainfall events.

The amount and nature of the fuel load is insufficient to carry fires and fires are rare within the biome. The large historical herds of Springbok and other game no longer exist. Like the many bird species in the area - mainly larks - the game was probably nomadic between patches of rainfall events within the biome. The Brown Locust and Karoo Caterpillar exhibit eruptions under similarly favourable, local rainfall events, and attract large numbers of bird and mammal predators.

Less than 1% of the biome is conserved in formal areas. The Prickly Pear (*Opuntia aurantiaca)* and Mesquite (*Prosopis glandulosa)* are the major alien invader species. Urbanization and agriculture are minimal, and irrigation is confined to the Orange River valley and some pans. Most of the land is used for grazing, by sheep (for mutton, wool and pelts) and goats, which can be commensurate with conservation. However, under conditions of overgrazing, many indigenous species may proliferate, including Three thorn (*Rhigozum trichotomum)*, Bitterbos (*Chrysocoma ciliate)* and Sweet Thorn (*Acacia karroo)*, and many grasses and other palatable species may be lost. There are very few rare or Red Data Book plant species in the Nama Karoo Biome. Tourism potential is low. Mining is important in the Biome.

Most of the research into the dynamics of the biome has been done in the east of the region, with the Grootfontein Agricultural Station at Middelburg featuring prominently. Consequently, little research in the west of the biome has been undertaken.

Succulent Karoo

The Succulent Karoo Biome has an equal status to the other biomes in South Africa - it is not a subtype of "a Karoo Biome."

Most of the biome covers a flat to gently undulating plain, with some hilly and "broken" veld, mostly situated to the west and south of the escarpment, and north of the Cape Fold Belt. The altitude is mostly below 800 m, but in the east it may reach 1 500 m. A variety of geological units occur in the region. There is little difference between the soils of the Succulent Karoo and Nama Karoo Biomes - both are lime-rich, weakly developed soils on rock. The Olifants and Doring Rivers are the major drainage systems in the west, with the Gouritz River in the south-east of the biome.

The Succulent Karoo Biome is primarily determined by the presence of low winter rainfall and extreme summer aridity. Rainfall varies between 20 and 290 mm per year. Because the rains are cyclonic, and not due to thunderstorms, the erosive power is far less than of the summer rainfall biomes. During summer, temperatures in excess of 40°C are common. Fog is common nearer the coast. Frost is infrequent. Desiccating, hot, Berg Winds may occur throughout the year.

The vegetation is dominated by dwarf, succulent shrubs, of which the Vygies (Mesembryanthemaceae) and Stonecrops (Crassulaceae) are particularly prominent. Mass flowering displays of annuals (mainly Daisies Asteraceae) occur in spring, often on degraded or fallow lands. Grasses are rare, except in some sandy areas, and are of the C3 type. The number of plant species mostly succulents - is very high and unparalleled elsewhere in the world for an arid area of this size.

Little data are available for the fauna of the Succulent Karoo. Of importance in the area are heuweltjies, raised mounds of calcium-rich soil, thought to have been created by termites. These often support distinctive plant communities.

The area has little agricultural potential due to the lack of water. The paucity of grasses limits grazing, and the low carrying capacity requires extensive supplementary feeds. Much soil has been lost from the biome, through sheet erosion, as a consequence of nearly 200 years of grazing. Ostrich farming, with considerable supplementary feeding, is practised in the Little Karoo in the south of the biome. In areas adjoining the Fynbos Biome, wine grapes, fruit and other crops are cultivated using the Fynbos water catchments. Tourism is a major industry: both the coastal scenery and the spring mass flower displays are draw cards. Mining is important, especially in the north.

Less than 0.5% of the area of the Succulent Karoo Biome has been formally conserved. The biome has a high number of rare and Red Data Book plant species. The high species richness and unique global status of the biome require urgent conservation attention. Fortunately, there are few invasive alien plants, with only Rooikrans (*Acacia cyclops)* a major problem in the southern coastal regions. Strip-mining for diamonds is destructive in the northern coastal regions, and legislation requiring revegetation of these areas is inadequate for near-desert conditions.

Fynbos

The Fynbos Biome is considered by many to be synonymous with the Cape Floristic Region or Cape Floral Kingdom. However, the "biome" refers only to the two key vegetation groups (Fynbos and Renosterveld) within the region, whereas both the "region" and the "kingdom" refer to the general geographical area and include other vegetation types in the Forest, Nama Karoo, Succulent Karoo and Thicket Biomes, but exclude peripheral outliers of the Fynbos Biome such as the Kamiesberg, North-western and Escarpment Mountain Renosterveld (59,60) and Grassy Fynbos (65) east of Port Elizabeth. However, the contribution of Fynbos vegetation to the species richness, endemicity and fame of the region is so overwhelming, that the Cape Floristic Region and Cape Floral Kingdom can be considered to be "essentially Fynbos."

The Cape Floral Kingdom is the smallest of the six Floral Kingdoms in the world, and is the only one contained in its entirety within a single country. It is characterized by its high richness in plant species (8 700 species) and its high endemicity (68% of plant species are confined to the Cape Floral Kingdom). The Cape Floral Kingdom thus compares with some of the richest floras worldwide, surpassing many tropical forest regions in its floral diversity.

In South Africa, over one third of all plant species occur in the Cape Floral Kingdom, even though the Kingdom occupies less than 6% of the area of the country. This is not primarily due to the large number of vegetation types in the Cape Floral Kingdom. Over 7 000 of the plant species occur in only five Fynbos vegetation types, with perhaps an additional 1 000 species in the three Renosterveld vegetation types. The contribution of Succulent and Nama Karoo, Thicket and Forest vegetation types in the region to the plant species diversity is thus relatively small. Thus, although the Cape Floral Kingdom contains five biomes, only the Fynbos Biome, comprising the Fynbos and Renosterveld vegetation groups, contains most of the floral diversity. Furthermore, the Cape Floral Kingdom traditionally does not include the Fynbos and Renosterveld vegetation outliers to the north and east. Including these would mean that endemicity would approach 80%, the highest level of endemicity on any subcontinent.

Distressingly, some three-quarters of all plants in the South African Red Data Book occur in the Cape Floral Kingdom: 1 700 plant species are threatened to some extent with extinction! This is much more than one would expect based on either the area of the Kingdom (6%) or its plant numbers (36%). This again reflects the unique nature of Fynbos vegetation: many Fynbos species are extremely localized in their distribution, with sets of such localized species organized into "centres of endemism." The city of Cape Town sits squarely on two such centres of endemism and several hundred species are threatened by urban expansion. However, a more serious threat is alien plants, which infest large tracts of otherwise undisturbed mountains and flats: their impact on these extremely localized species is severe. Aliens are thus the major threat to Fynbos vegetation and its plant diversity, especially in the mountains. On the lowlands and on the less steep slopes the major threat is agriculture - new technologies, fertilisers and crops are steadily eating into our floral reserves. Another important threat is the misuse of fire. Fynbos must burn, but fires in the wrong season (such as in spring, instead of late summer) or too frequently (so that plants do not have time to set seed) eliminate species. Several factors influence fire dynamics in Fynbos - global warming, grazing practices and fire management (ignition events, size of burns), but their relative importance and interactions are poorly understood.

The two major vegetation groupings in Fynbos are quite distinct and have contrasting ecological systems. Essentially, Renosterveld used to contain the large animals in the Cape Floristic Kingdom, but these are now extinct or else have been reintroduced into conservation areas. By contrast, Fynbos is much richer in plant species, but has such poor soils that it cannot support even low densities of big game. However, most of the endemic amphibian, bird and mammal species in the region, occur in Fynbos vegetation types. The study are falls only within the Renosterveld part of this biome.

APPENDIX B

Vegetation types

February 2011
Report No. 1280012800-10444-21

Golder Associates

Upper Karoo Hardeveld NKu2

Synonyms Arid Karoo and Desert False Grassveld (23%), F 27 central Upper Karoo (15%), VT 26 Karroid Broken Veld (12%), Vi 35 False Arid Karoo (12%) (Acocks 1953). LR 50 Upper Nama Karoo (31 %), LR 49 Bushmanland Nama Karoo (23%) (Low & Rebelo 1996).

Distribution Northern, Western and Eastern Cape Provinces: Discrete areas of slopes and ridges including dolerite dykes and sills in the region spanning Middelpos in the west and Strydenburg, Richmond and Nieu-Bethesda in the east. Most crest areas and steep slopes of the Great Escarpment facing south between Teekloofpas (connecting Leeu-Gamka and Fraserburg) and eastwards to Graaff-Reinet. Altitude varies mostly from 1 000—1 900 m.

Vegetation & Landscape Features Steep slopes of koppies, butts, mesas and parts of the Great escarpment covered with large boulders and stones supporting sparse dwarf Karoo scrub with drought-tolerant grasses of genera such as *Aristida, Eragrostis* and *Stipagrostis.*

Climate In the western part of its area this unit experiences the same climate as the Western Upper Karoo. In the eastern part the climate is very close to that of Karoo Escarpment. The MAP ranges from about 1 50 mm in the northwest to 350 mm along some grassland margins on the Great Escarpment and in the east. Water concentrates between rocks as a result of rainfall runoff. Incidence of frost is relatively high, but ranging widely from <30 days per year at lower altitudes to >80 days at highest altitudes.

Important Taxa

Tall Shrubs: *Lycium cinereurn* (d), *Rhigozum obovatum* (d), *Cadaba aphylla, Diospyros austro-africana, Ehretia rigida* subsp. *rigida, Lyciurn oxycarpum, Melianthus cornosus, Rhus burchellii.*

Low Shrubs: *Chrysocoma ciliata* (d), *Eriocephalus ericoides* subsp. *ericoides* (d), *Euryops lateritiorus* (d), *Felicia rnuricata* (d), *Limeurn aethiopicurn* (d), *Pteronia glauca* (d), *Arnphiglossa tnt/bra, Aptosimurn e/ongaturn, Tetragonia arbuscula, Wahlenbergia tenella.*

Succulent Shrubs: *Aloe broomii, Drosanthernurn lique, Faucania bosscheana, Kleinia longiflora, Pachypodium succulentum, Trichodiadema barbatum, Zygophyllum flexuosum.* Semiparasitic Shrub: *Thesium lineatum* (d). Herbs: *Troglophyton capillaceum* subsp. *capilaceum, Dianthus caespitosus* subsp. *caespitosus, Gazania krebsiana, Lepidiurn atnicanum* subsp. *atricanum, Leysera tenella, Pelargonium minimum, Sutera pinnat/tida, Tribulus tenrestnis.* Geophytic Herbs: *Albuca setosa, Androcymbium albomarginaturn, Asplenium cordatum, Boophone disticha, Cheilanthes bergiana, Drimia intricata, Oxalis depressa,* Graminoids: *Aristida adscensionis* (d), *A. congesta* (d), *A. diffusa* (d), *Cenchrus ciliaris* (d), *Enneapogon desvauxii* (d), *Eragrostis lehmanniana* (d), *E. obtusa* (d), *Sporobo/us flrnbniatus* (d), *St/pa grostis obtusa* (d), *Cynodon incompletus, Digitaria eriantha, Ehrharta calycina, Enneapogon scaberi, F. scoparius, Era grostis cunvu/a, F. nindensis. F. procumbens, Fin gerhuthia africana, Heteropogon con tontus, Merxrnuellera disticha, Stipagrostis cillata, Themeda triandra, Tragus benteronianus, T koelerioides.*

Endemic Taxa Succulent Shrubs: *Aloe chlorantha, Crassula barbata* subsp. *broomii, Delosperma robustum, Sceletium expansum, Stomatium suaveolens.* Low Shrubs: *Cineraria polycephala, Euryops petraeus, Lotononis azureoides, Selago magnakarooica.* Tall Shrub: *Anisodontea malvastroides.* Herbs: *Cineraria arctotidea, Vellereophyton niveum.* Succulent Herbs: *Adromischus tallax, A. humilis.* Geophytic Herbs: *Gethyllis longistyla, Lachena/ia auriolae, Ornithogaium paucifolium* subsp. *karooparkense.*

Conservation Least threatened. Target 21%. Only about 3% statutorily conserved in Karoo National Park and Karoo Nature Reserve. Small percentage also protected in private reserves such as Rupert Game Farm. Erosion is moderate (64%) and high (2%).

Remarks One of the richer floras of the Nama-Karoo Biome, this type also contains a substantial number of diagnostic species relative to the surrounding extensive flats (i.e. the Eastern, Northern and Western Upper Karoo vegetation units). Examples are the widespread occurrence of *Asparagus mucronatus, A. striatus, Cissampelos capensis, Pachypodium succulentum,*

Gamka Karoo NKI1

VT 26 Karroid Broken Veld (76%) (Acocks 1953). LR 53 Great Nama Karoo (70%) (Low & Rebelo 1996). BHU 91 Gamka Broken Veld (cowling & Heijnis 2001).

Distribution

Western Cape and Eastern . Cape Provinces and marginally into the Northern Cape Province: Large basin between the Great Escarpment (Nuweveld Mountains) in the north and northwest and Cape Fold Belt Mountains (mostly Swartberg Mountains) in the south. From approximately the edge of the Gamka basin catchment area (i.e. of the Dwyka River tributary) in the west to about the Kariega River in the east. Altitude varies mostly from 500—1 100 m.

Vegetation & Landscape Features

Extremely irregular to slightly undulating plains covered with dwarf spiny shrubland dominated by Karoo dwarf shrubs (e.g. *Chrysocorna ciliata, Eriocephalus ericoides)* with rare low trees (e.g. *Euclea undulata).* Dense stands of drought-resistant grasses *(Stipagrostis, Aristida)* cover (especially after abundant rains) broad sandy bottomlands.

Climate

One of the most arid units of the Nama-Karoo Biome. Rainfall mainly in autumn and summer, with a marked peak in March and low levels of cyclonic rain in winter. This region is in the rainshadow of Cape Fold Belt mountains in the south, MAP ranging from about 100 mm in some areas between the Dwyka and Gamka Rivers to about 240 mm against the Great Escarpment. Mean maximum and minimum monthly temperatures in Beaufort West are 38.7°C and —3.2°C for January and July, respectively. Strong northwesterly winds occur in winter.

Important Taxa

Tall Shrubs: *Lycium cinereum* (d), *L. oxycarpum* (d), *Rhigozurn obovatum* (d), *Acacia karroo, Cadaba aphylla, Lycium schizocalyx, Rhus burchelli.*

Low Shrubs: *Chrysocorna cilliata* (d), *Eriocephalus ericoides* subsp. *ericoides* (d), *F. spinescens* (d), *Fellcia muricata* (d), *Galenia fruticosa* (d), *Lirneum aethiopicum* (d), *Pentzia incana* (d), *Pteronia adenocarpa* (d), *Rosenia humullis* (d), *Asparagus burchellil, Blepharis mitrata, Eriocephalus microphyllus* var. *pubescens, Fellicia muricata* subsp. *cinerascens, Galenia secunda, Garuleurn bipinnatum, G. latifolium, Gomphocarpus fillformis, Hellchrysium luciloides, Herrnannia desertorurn, H. grandiflora, H. spinosa, Melolobium candicans, Microloma armatum, Pentzia pinnatisecta, Plinthus karooicus, Polygala seminula, Pteronia glauca, P sordida, P viscosa, Selago geniculata.*

Succulent Shrubs: *Ruschia intricata* (d).*Qassula rnuscosa, Galenia sarcophylla, Kleinia longiflora,Ruschia spinosa, Salsola tuberculata.*

Herbs: *Gazania lichtensteinii* (d), *Charnaesyca inaequilatera, Dicorna capensis, Galenia glandulifera, Lepidiurn africanurn* subsp. *africanurn, L. desertorum, Lessertia pauciflora, Tribulus terrestris, Ursinia nana.* Geophytic Herbs: *Drirnia intricata, Moraea polystachya.*

Graminoids: *Aristida congesta* (d), *A. diffusa* (d), *Fingerhuthia africana* (d), *Stipagrostis ciliata* (d), *S. obtusa* (d), *Aristida adscensionis, Cenchrus ciliaris. Digitaria argyrograpta, Enneapogon desvauxii, Enneapogon scaber.*

Biogeographically Important Taxa (*Endemic to Great Karoo Basin) Succulent Shrubs: *Hereroa latipetala** (also found in Prince Albert Succulent Karoo), *H. odorata** (also found in Koedoesberge-Moordenaars Karoo), *Pleiospilos cornpactus* (southern and western limits of distribution), *Rhinephyllum luteum*, Stapelia engleriana**. Geophytic Herb: *Tritonia tugwelliae**. Low Shrub: *Fellcia lasiocarpa**. Succulent Herbs: *Piaranthus cornptus*, Tridentea parvipuncta* subsp. *parvipuncta**. Graminoid: *Oropetiurn capense* (westernmost limit of distribution).

Endemic Taxa Succulent Shrubs: *Chasmatophyllum stanleyi. Hereroa incurva, Hoodia drega Ruschia beaufortensis.* Shrubs: *Jarnesbrittenia tenuifolia.* Herb: *Manulea karrooica.* Succulent Herb: *Piaranthus cornptus.*

Conservation Least threatened. Target 16%. About 2% statutorily conserved in the Karoo National Park and some in pnvate reserves, such as Steenbokkie Private Nature Reserve (near Beaufort West). Only small part has undergone transformation. The alien *Salsola kali* is a serious infestation problem locally. Erosion is moderate (78%), low (11%) and high (11 **%).**

Eastern Upper Karoo NKu4

VT 36 False Upper Karoo (54%) (Acocks 1953). LR 52 Eastern Mixed Nama Karoo (61%) (Low & Rebelo 1996)

Distribution Northern Cape, Eastern Cape and Western Cape Provinces: Between Carnarvon and Loxton in the west, De Aar, Petrusville and Venterstad in the north, BUrgersdorp, Hofmeyr and Cradock in the east and the Great Escarpment and the Sneeuberge-Coetzeesberge mountain chain in the south. Altitude varies between mostly 1 000—1 700 m.

Vegetation & Landscape Features Flats and gently sloping plains (interspersed with hills and rocky areas of Upper Karoo Hardeveld in the west, Besemkaree Koppies Shrubland in the northeast and Tarkastad Montane Shrubland in the southeast), dominated by dwarf microphyllous shrubs, with 'white' grasses of the genera *Aristida* and *Eragrostis* (these become prominent especially in the early autumn months after good summer rains). The grass cover increases along a gradient from southwest to northeast.

Climate Rainfall occurs mainly in autumn and summer, peaking in March. MAP ranges from about 180 mm in the west to 430 mm in the east. Incidence of frost is relatively high, but ranging widely from <30 days (in the lower-altitude Cradock area) to >80 days of frost per year (bordering the Upper Karoo Hardeveld on the Compassberg and mountains immediately to the west). Mean maximum and minimum monthly temperatures in Middelburg (Grootfontein) are 36.1°C and —7.2°C for January and July, respectively. Corresponding values are 37°C and —8°C for Victoria West and 36.6°C and —4.2°C for Hofmeyr.

Important Taxa Tall Shrubs: *Lycium cinereum* (d), *L. horridum, L. oxycarpum.* Low Shrubs: *Chrysocoma ciliata* (d), *Eriocephalus ericoides* subsp. *ericoides* (d), *F. spinescens* (d), *Pentzia globosa* (d), *P. incana* (d), *Phymaspermum parvifolium* (d), *Salsola calluna* (d), *Aptosimum procumbens, Feilicia muricata, Gnidia polycephala, Helichrysum dregeanum, H. lucilioides, Limeum aethiopicum,* Nenax *microphylla, Osteospermum leptolobum, Plnithus karooicus, Pteronia glauca, Rosenia humilis, Selago geniculata, S. saxatilis.* Succulent Shrubs: *Euphorbia hypogaea, Ruschia intricata.* Herbs: *Indigofera alternans, Pelargonium minimum, Tribulus terrestris.* Geophytic Herbs: *Moraea pallida* (d), *Moraea polystachya, Syringodea bifucata, S. concoior.* Succulent Herbs: *Psilocaulon corlarium, Tridentea jucunda, T virescens.* Graminoids: *Aristida congesta* (d), *A. diffusa* (d), *Cynodon incompletus* (d), *Eragrostis bergiana* (d), *E. bicolor* (d), *E. Jehmanniana* (d), *E. obtusa* (d), *Sporobolus fimbriatus* (d), *Stipagrostis ciliata* (d), *Tragus koelerioides* (d), *Aristida adscensionis, Chloris virgata, Cyperus usitatus, Digitaria eriantha, Enneapogon desvauxii, E. scoparius, Eragrostis curvula, Fin gerhuthia africana, Heteropogon contortus, Sporobolus ludwigii, S. tenellus, Stipagrostis obtusa, Themeda triandra, Tragus berteronianus.*

Endemic Taxa Succulent Shrubs: *Chasmatophyllum rouxii, Hertia cluytifolia, Rabiea albinota, Salsola tetrandra.* Tall Shrub: *Phymaspermum scoparium.* Low Shrubs: *Aspalathus aclcuiaris* subsp. *plantolla, Selago persimius, S. walpersii.*

Conservation Least threatened. Target 21%. Statutorily conserved in Mountain Zebra and Karoo National Parks as well as in Oviston, Commando Drift, Rolfontein and Gariep Dam Nature Reserves. About 2% of the unit has been transformed, largely due to building of dams (Gariep, Grassridge, Killowen, Kommandodrift, Kriegerspoort, Lake Arthur, Modderpoort, Schuil Hoek, Vanderkloof, Victoria West, Wonderboom and Zoetvlei). *Medicago laciniata* is a common and widespread alien plant. Erosion is moderate (60%) and high (38%). Veld managers perceive much of the Eastern Upper Karoo to be experiencing changes in species composition requiring high-priority action (Hoffman et al. 1999).

Remarks This vegetation type has the largest mapped area of all vegetation units. The regions between Colesberg (Northern Cape) and Springfontein (Free State) fall within a broad ecotone where grassy Eastern Upper Karoo grades into Ghariep Karroid Grassland.

Southern Karoo Riviere AZi6

Including Mesic Riparian Bush & Xeric Riparian Bush (Van der Walt 1980). Riparian Thicket (Palmer 1991). *Lycium cinereum-Salsola aphylla* Shrubland *& Acacia karroo-Stipagrostis namaquensis* Riparian Woodland (Rubin & Palmer 1996). *Becium burchellianum-Acacia karroo* Woodland (Brown & Bezuidenhout 2000).

Distribution

Western and Eastern Cape Provinces: Alluvia of the Buffels, Bloed, Dwyka, Gamka, Sout, Kariega, and Sundays Rivers and their tributaries), east of Laingsburg as far west as Graaff-Reinet and Jansenville. This vegetation unit is embedded within the Koedoesberge-Moordenaars Karoo, Prince Albert Succulent Karoo, Gamka Karoo, Eastern Lower Karoo, and southern parts of the Eastern Upper Karoo as well as some parts of the Albany Thicket Biome south of Cradock. Altitude ranging from 250—1 550 m.

Vegetation & Landscape Features

Narrow riverine flats supporting a complex of Acacia *karroo* or *Tamarix usneoides* thickets (up to 5 m tall), and fringed by tall Salsola-dominated shrub- land (up to 1 .5 m high), especially on heavier (and salt-laden) soils on very broad alluvia. In sandy drainage lines *St/pagrostis namaquensis* may occasionally also dominate. Mesic thicket forms in the far eastern part of this region (see Van der Walt 1980: Table 4) may also contain *Leucosidea sericea, Rhamnus prinoides* and *Ehrharta erecta.*

Climate

Transitional, bimodal (equinoctial) rainfall patterns with peaks in March (major) and November (minor). Climate is subarid on the whole, with overall MAP of 243 mm (range from 165 mm in the Gamka Karoo basin to 430 mm in the vicinity of Bedford). Overall warm-temperate regime, with MAT of 16.3°C, ranging from 14.6°C (Upper Karoo) to 18.3°C (upper reaches of Sundays River). Frost occurs frequently in winter.

Important Taxa

Riparian thickets

Small Trees: Acacia *karroo* (d), *Rhus lancea* (d). Tall Shrubs: *Diospyros lyciodes* (d), *Tamarix usneoides* (d), *Cadaba aphylla, Euclea undulata, Grewia robusta, Gymnosporia buxifolia, Melianthus comosus.* Low Shrub: *Asparagus striatus.* Succulent Shrubs: *Lycium cinereum* (d), *Amphiglossa callunoides, Lycium hirsutum, L. oxycarpum.*

Rocky slopes of river canals

Graminoid: *Stipagrostis namaquensis* (d).

Alluvial shrublands & herblands

Low Shrubs: *Bailota africana, Bassia salsoloides, Carissa haematocarpa, Pentzia incana.* Succulent Shrubs: *Malephora uitenhagensis* (d), *Salsola aphylla* (d), *S. arborea* (d), *Drosanthemum, Salsola geminiflora, S. gemmifera.* Graminoids: *Cynodon incompletus* (d), *Cenchrus ciliaris, Cyperus marginatus.*

Reed beds

Megagraminoid: *Phragmites australis* (d).

Endemic Taxon Alluvial shrublands & herblands

Graminoid: *Isolepis expahlescens.*

Conservation

Least threatened. Target 24%. Only about 1 .5% statutorily conserved in the Karoo National Park as well as in the Aberdeen, Bosberg, Commando Drift, Gamkapoort and Karoo Nature Reserves and in about 10 private reserves, mainly set up for game farming. Some 12% transformed for cultivation and building of dams, including Beaufort West, Beervlei, De Hoop, Floriskraal, Kommandodrift, Lake Arthur, Leeu-Gamka, Mentz and Vanryneveldspas Dams. Frequent disturbance (floods, concentrated grazing pressure), and associated input of nutrients, increase vulnerability of these habitats to invasion of alien woody species such as *Agave americana, Opuntia* species, *Prosopis* species, *Sahix babylonica* and *Schinus sp,* and forbs including *Atriplex, Cirsium vulgare, Salsola kali* and *Sehkuhria pinnata.*

Eastern Lower Karoo NKI2

VI 30 central Lower Karoo (43%), VT 26 Karroid Broken Veld (31%) (Acocks1953). LR 54 central Lower Nama Karoo (94%) (Low & Rebelo 1996). Grass Dwarf Shrublands of the Camdeboo and Aberdeen plains, Dwarf Shrublands (typicum) of the Camdeboo & Succulent Dwarf Shrubland (Palmer 1991a).

Distribution

Eastern Cape and Western Cape Provinces: Plains east of the Kariega and Buffels Rivers in the area south of the Camdebo Mountains and the line of mountains linking to the Coetzeesberge encompassing Aberdeen, Graaff-Reinet and Pearston (region called Camdebo) and plains south of Aberdeer to Klipplaat and Miller. Contains some higher elevation islands of Camdebo Escarpment Thicket, Groot Thicket and Lower Karoo Gwarrieveld. Altitude varies mostly from 500—1 100 m.

Vegetation & Landscape Features

Plains interrupted by some dolerite dykes, butts and mesas. The dominating vegetation is low to middle-height microphyllous shrubland with drought-resistant 'white' grasses becoming abundant in places, especially on sandy and silty bottomlands. Leaf-succulent dwarf shrubs of the families Aizoaceae and Crassulaceae can also be encountered.

Climate

Rainfall mostly in late summer and early autumn, with main peak in March. MAP ranges from about 150 mm in the west to 350 mm in the east. Mean maximum and minimum monthly temperatures for Graaff-Reinet are 38.6°C and —0.3°C for January and July, respectively.

Important Taxa

Small Trees: Acacia *karroo.*

Tall Shrubs: *Lycium cinereum* (d), *L. oxycarpum* (d), *adaba Caphylla, arissa haematocarpa, Grewia robusta, Lycium schizocalyx, Rhigozum obovatum.* Low Shrubs: *Eriocephalus ericoides* subsp. ericoides (d), *Fellcia muricata* (d), *Pentzia incana* (d), *Rosenia humllis* (d), *Aptosimum elongatum, Asparagus striatus, A. suaveolens, Barleria pun gens, Blepharis capensis, B. mitrata, Chrysocoma cillata, Euryops anthemoides, Fellcia muricata, Galenia secunda, Garuleum la tifolium, Helichrysum zeyheri, Herman nia cuneifolia, Indigo [era sessilifolia, Limeum aethiopicum, Microloma armatum, Pegolettia retrofracta, Phymaspermum parvifolium, Plin thus karooicus, Polygala seminuda, Pteronia adenocarpa, P glauca, P sordida, Selago fruticosa, Senecio acutifollus, Sutera halimifolia, Zygophyllum microphyllum.*

Succulent Shrubs:
Ruschia cradockensis subsp. *cradockensis* (d), *Astroloba follolosa, Crassula corallina, Drosanthemum sp, D. subspinosum, Euphorbia ferox, Mestoklema tuberosum, Pachypodium succulen tum, Rhombophyllum nelii, Sarcocaulon camdeboense, S. patersonii, Trichodiadema barbatum.*

Semiparasitic Shrub:
Thesium hystrix,

Graminoids: *Aristida adscensionis* (d), *A.* congesta (d), *Eragrostis lehmanniana* (d), *E. obtusa* (d), *Tragus berteronianus* (d), *T koelerloides* (d), *T racemosus* (d), *A. diffusa, Chloris virgata, Cynodon incompletus, Enneapogon desvauxii, Era grostis curvula, Stipa grostis obtusa.*

Herbs: *Chamaesyce inaequilatera, Convolvulus sagittatus, Gazania krebsiana, Lepidium africanum* subsp. *africanum, Tribulus terrestris.*

Succulent Herbs: *Crassula muscosa, Psilocaulon articulatum, P corlarium, Senecio radicans.*

Geophytic Herbs: *Albuca setosa, Drimia anomala, D. intricata, Moraea polystachya.*

Endemic Taxa

Succulent Shrubs: *Aloinopsis rubrolineata, Chasmatophyllum nelii, Cylindrophyllum calamiforme, Euphorbia coerulans, Ruschia vanderbergiae.* Succulent Herbs:
Haworthia decipiens var. *cyanea, H. greenii.*

Conservation

Least threatened. Target 16%. Some of patches statutorily conserved in Aberdeen and Karoo Nature Reserves as well as in private reserves such as Minnawill Game Farm. Between 1 % and 2% transformed by alien infestation. Erosion
is high (45%) and moderate (45%).

Remarks

Vegetation structure of the Eastern Lower Karoo differs from the Gamka Karoo with its higher proportion of succulent dwarf shrubs (species of *Ruschia)* and higher frequency of larger woody shrubs *(Diospyros, Euclea, Lycium, Rhus)* associated with rocky outcrops and other mesic patches.

Northern Upper Karoo NKu3

VI 35 False Arid Karoo (35%), VT 36 False upper Karoo (27%) (Acocks, 1**953).** LR 50 Upper Nama Karoo (44%), LR 52 Eastern Mixed Nama Karoo (24%) (Low & Rebelo 1996).

Distribution

Northern Cape and Free State Provinces: Northern regions of the Upper Karoo plateau from Prieska, Vosburg and Carnarvon in the west to Philipstown, Petrusville and Petrusburg in the east. Bordered in the north by Niekerkshoop, Douglas and Petrusburg and in the south by Carnarvon, Pampoenpoort and De Aar. A few patches occur in Griqualand West. Altitude varies mostly from 1 000—1 500 m.

Vegetation & Landscape Features

Shrubland dominated by dwarf karoo shrubs, grasses and Acacia *mellifera* subsp. *detinens* and some other low trees (especially on sandy soils in the northern parts and vicinity of the Orange River). Flat to gently sloping, with isolated hills of Upper Karoo Hardeveld in the south and Vaalbos Rocky Shrubland in the northeast and with many interspersed pans.

Climate

Rainfall peaks in autumn (March). MAP ranges from about 190 mm in the west to 400 mm in the northeast. Mean maximum and minimum monthly temperatures for Britstown are 37.9°C and —3.6°C for January and July, respectively. Corresponding values are 37.1°C and —4.8°C for De Aar and 39.0°C and —2.3°C for Kareekloof (northwest of Strydenburg).

Important Taxa

Small Trees: Acacia *mellifera* subsp. *detinens, Boscia albitrunca.*

Tall Shrubs: *Lycium cinereum* (d), *L. horridum, L. oxycarpum, L. schizocalyx, Rhigozum trichotomum.*

Low Shrubs: *Chrysocoma cilliata* (d), *Gnidia polycephala* (d), *Pentzia* calcarea (d), P. *globosa* (d), *P incana* (d), *P spinescens* (d), *Rosenia humilis* (d), *Amphiglossa triflora, Aptosimum marlothii, A. spinescens, Asparagus glaucus, Barleria rigida, Berkheya annectens, Eriocephalus ericoides* subsp. *ericoides, E. glandulosus, E. spinescens, Euryops aspara goides. Feilcia muricata, Helichrysum luciloides, Hermannia spinosa, Leucas capensis, Limeum aethiopicum, Melolobium candicans, Microloma arma tum, Osteospermum leptolobum, 0. spinescens, Pegolettia retrofracta, Pen tzia lanata, Phyllanthus maderaspatensis, Plin thus karooicus, Pteronia glauca, P sordida, Selago geniculata, S. saxatilis, Tetragonia arbuscula, Zygophyllum lichtensteinianum.*

Succulent Shrubs: *Hertia pallens, Salsola calluna, S. glabrescens, S. rabieana, S. tuberculata, Zygophyllum flexuosum.*

Semi parasitic Shrub: *Thesium hystrix* (d),

Herbs: *Chamaesyce inaequllatera, Con volvulus sagittatus, Dicoma capensis, Gazania krebsiana, Hermannia comosa, indigofera altemans, Lessertia pauciflora, Radyera urens, Sesamuth capense, Sutera pinnatifida, Tribulus terrestrls, Vahlia capensis.*

Succulent Herb: *Psilocaulon coriarium.* Geophytic Herb: *Moraea* pallida.Graminoids: *Aristida adscensionis* (d), *A. con gesta* (d), *A. diffusa* (d), *Enneapogon desvauxii* (d), *Eragrostis lehmanniana* (d), *E. obtusa* (d), *E. truncata* (d), *Sporobolus fimbriatus* (d), *Stipagrostis obtusa* (d), *Era grostis* bicolor, *E. porosa, Fingerhuthia africana, Heteropogon con tortus, Stipa grostis ciliata, Themeda triandra, Tragus berteronianus, T koelerioides, T racemosus.*

Biogeographically Important Taxa

Herb (western distribution limit): *Convolvulus boedeckerianus.* Tall Shrub (southern limit of distribution): *Gymnosporia szyszyiowiczii* subsp. *namibiensis.*

Endemic Taxa

Succulent Shrubs: *Lithops hookeri, Stomatium pluridens.* Low Shrubs: *Atriplex spongiosa, Galenia exigua.* Herb: *Manulea deserticola.*

Conservation

Least threatened. Target 21%. None conserved in statutory conservation areas. About 4% has been cleared for cultivation (the highest proportion of any type in the Nama-Karoo) or irreversibly transformed by building of dams (Houwater, Kalkfontein and Smart Syndicate Dams). Areas of human settlements are increasing in the northeastern part of this vegetation type (Hoffman et al. 1999). Erosion is moderate (46.2%), very low (32%) and low (20%). *Prosopis glandulosa,* regarded as one of the 12 agriculturally most important invasive alien plants in South Africa, is widely distributed in this vegetation type (Hoffman et al. 1999). *Prosopis* occurs in generally isolated patches, with densities ranging from very scattered to medium (associated with the lower Vaal River drainage system and the confluence with the Orange River) to localised closed woodland on the western border of the unit with Bushmanland Basin Shrubland.

Remark

This Karoo unit is found on floristic and ecological gradients between the Nama-Karoo, arid Kalahari savanna and arid highveld grasslands.

Karoo Escarpment Grassland Gh1

VT 60 Karroid *Danthonia* Mountain Veld (69%)(Acocks 1953). LR 44 Southeastern Mountain Grassland (69%) (Low & Rebelo 1996).

Distribution

Eastern, Northern and Western Cape Province: Occurs on the Karoo Escarpment, running in an east-west direction from Molteno to Noupoort in the north, and from Somerset East in a northwesterly direction towards Nieu-Bethesda. Also found on the north-facing slopes of the Winterberg Mountains around Tarkastad. The

westernmost locality is on the highest-altitude flat-topped mesas of the Escarpment in the Karoo National Park near Beaufort West. Altitude about 1100—2 502 m at the summit of the Kompasberg.

Vegetation & Landscape Features

Mountain summits, low mountains and hills with wiry, tussock grasslands, usually dominated by *Merxmuellera disticha.* Other common species include the grasses typical of dry grasslands (genera *Eragrostis, Tetrachne, Karroochloa, Helictotrichon, Melica, Tragus, Elion urus* and *Aristida).* An important low shrub component occurs throughout this grassland unit.

Climate

Rainfall showing minor (possibly insignificant) peaks in March and November—December. Very dry winters. MAP 300— 580 mm, increasing from west to east as well as with increasing elevation. The coefficient of variation of MAP 27—36% across the unit. The incidence of frost is from less than 20 to more than 100 days, the higher values occurring at higher elevation. There may be a number of days of snow per year, especially at higher elevations and near the edge of the Great Escarpment.

Important Taxa

Graminoids: *Aristida congesta* (d), *A. diffusa* (d), *Cynodon incompletus* (d), *Ehrharta calycina* (d), *Eragrostis chioromelas* (d), *Heteropogon con tortus* (d), *Merxmuellera disticha* (d), *Themeda triandra* (d), *Tragus koelerioides* (d), *Cymbopogon pospischilH, Cynodon dactylon, Elionurus muticus, Era grostis curvula, F. lehmanniana, E. obtusa, Eustachys paspaloides, Karroochloa purpurea, Melica decumbens, Panicum stapfianum, Tetrachne dregei.*

Herbs: *Berkheya pinnatifida, Con volvulus sagitta tus, 0lan thus caespitosus* subs p. *caespitosus, Diascia capsularis. Dimorphotheca zeyheri, Galium capense* subsp. *capense, Gazania krebsiana* subsp. *krebsiana, Hebenstretia dentata, Helichrysum nudifolium* var. *nudifo lium, H. tysonii, Lasiospermum bipinnatum, Lepidium africanum* subsp. *africanum, Rumex lanceolatus,* Senecio *asperulus.*

Geophytic Herbs: *Boophone disticha, Cheilanthes bergiana, C. hirta, Eucomis autumnalis* subsp. *autumnalis, Haemanthus humilis* subsp. *humilis, Oxalis depressa.*

Succulent Herb: *Tripteris aghillana* var. *integrifolia.*

Low Shrubs: *Chrysocoma ciliata* (d), *Felicia muricata* (d), *Anthospermum rigidum* subsp. *pumilum, A triplex semibaccata* var. *appendiculata, Elytropappus rhinocerotis, Erica caespitosa, E. caffrorum* var. *caffrorum, F. woodii, Eriocephalus eximius, Euryops annae, F. anthemoides* subsp. *astrotrichus, E. candollei, E. floribundus, F. oligoglossus* subsp. *oligoglossus, Felicia filifolia* subsp. *filifolia, Helichrysum asperum* var. *albidulum, H. dregeanum, H. lucilioides, H. niveum, H. rosum, H. zeyheri, Indigo fera sessilifolia, Limeum aethiopicum, Nemesia fruticans, Passerina montana, Selago albida, S. saxatilis, Senecio burchellii, Sutera pinnatifida, Wahlenbergia albens.*

Succulent Shrubs: *Euphorbia clavarioides* var. *clavarioides, E. mauritanica.* Tall Shrubs: *Ciiffortia arborea, Diospyros austro-africana, Rhus lucida.*

Biogeographically Important Taxa

Graminoids: *Pentaschistis cirrhulosaD, P microphyllaD.* Low Shrubs: *Helichrysum* sessileD, *Pentzia cooperi°.* Succulent Shrub: *Delosperma con gestumD.* Succulent Herb: *Duvalia modestaC.*

Endemic Taxa

Graminoid: *Schoenoxiphium rufum* var. *dregeanum.* Herbs: *Lithospermum diversifolium, Wahlenbergia sphaerica.* Geophytic Herbs: *Knipho fia acraea, Syringodea pulchella.* Low Shrubs: *Euryops dentatus, E. trilobus, Helichrysum scitulum, Selago bolusii.* Succulent Shrub: *Delosperma gramineum.*

Conservation

Least threatened. Target 24%. Nearly 3% statutorily conserved in the Mountain Zebra and Karoo National Parks as well as in the Tsolwana and Karoo Nature Reserves. Slightly higher portions also protected in

game farms and private nature reserves, such as Buchanon, Asanta Sana, Samara, Karoo Safaris, Hoeksfontien, Glen Harry, Oudekraal and Rupert.

This unit occurs across a wide geographical area with associated floristic variability. The biome classification of this unit is controversial since both Karoo and Grassland elements are strongly represented in the species composition. However, the presence of many (and dominant) C3 grasses surrounded by vegetation containing C4 grasses as well as the remarkable share of fyn bos-related elements *(Elytropappus rhinocerotis, Er/ca caffra, Cliffortia ramosissima, Ursinia montana, Pentzia cooperi, Euryops* species, *Passer/na montana, Cliffortia arborea* and also a new species of *Erica—E.G.H.* Oliver, personal communication) supports the decision to classify this vegetation within the Grassland Biome (see also Acocks 1988, Low & Rebelo 1996).
The mountain ranges with this arid type of grassland are one of the centres of diversification of the genus *Euryops* (Nordenstam 1968).

Besemkaree Koppies Shrubland Gh4

VT 36 False Upper Karoo (79%) (Acocks 1953). LR 52 Eastern Mixed Nama Karoo (76%) (Low & Rebelo 1996).

Distribution

Northern Cape, Free State and Eastern Cape Provinces: On plains of Eastern Upper Karoo (between Richmond and Middelburg in the south and the Orange River) and within dry grasslands of the southern and central Free State. Extensive dolerite-dominated landscapes along the upper Orange River belong to this unit as well. Extends northwards to around Fauresmith in the northwest and to the Wepener District in the northeast. Altitude 1 120—1 680 m.

Vegetation & Landscape Features

Slopes of koppies, butts and tafelbergs covered by two-layered karroid shrubland. The lower (closed-canopy) layer is dominated by dwarf small-leaved shrubs and, especially in precipitation-rich years, also by abundant grasses, while the upper (loose canopy) layer is dominated by tall shrubs, namely *Rhus erosa, R. burcheilli, R. ciliata, Euclea crispa* subsp. ovata, *Diospyros austro-africana* and *Olea europaea* subsp. *africana.*

Climate Due to the large extent of the area, the rainfall pattern differs slightly from west to east. Seasonal summer rainfall prevails when the patches are found embedded within other units of the Grassland Biome, but the southern and southwestern regions show hints of bimodal climate patterns typical of the Nama-Karoo. Far more importantly, despite an overall MAP of almost 400 mm, MAP ranges from about 280 mm in the west (De Aar) to more than double, 580 mm, in the east (Edenburg). Much of the rainfall is of convectional origin. MAT 15°C.

Important Taxa

Small Trees: *Cussonia paniculata, Ziziphus mucronata.*

Tall Shrubs: *Diospyros austro-africana* (d), *Euclea crispa* subsp. *ovata* (d), *Olea* europaea subsp. *africana* (d), *Rhus burchellii* (d), *R.* ciliata (d), *R. erosa* (d), *Buddieja saligna, Diospyros lycioides* subsp. *lycioides, Ehretia rigida, Grewia occiden tails, Gymnosporia polyacantha, Tarchonan thus minor.*

Low Shrubs: *Asparagus suaveolens* (d), *Chrysocoma ciliata* (d), *Amphiglossa triflora, Aptosimum elongatum, Asparagus striatus, Diospyros pallens, Eriocephalus ericoides, E. spinescens, Euryops empetrifolius, Felicia f muricata, Helichrysum dregean um, H. lucilioides, Hermannia multiflora, H. vestita, Lantana rugosa, Limeum aethiopicum, Lycium cinereum, Melolobium candicans, M. microphyllum, Nenax microphylla, Pegolettia retrofracta, Pen tzia globosa, Rhigozum obovatum, Selago saxatilis, Stachys linearis, S. rugosa, Sutera halimifolia, Wahlenbergia albens.*

Succulent Shrubs: Aloe *broomii, Chasmatophyllum musculinum,* C. *verdoorniae, Cotyledon orbiculata* var. *dactylopsis, Pachypodium succulen tum.* .

Graminoids: *Aristida adscensionis* (d), *A. con gesta* (d), *A. diffusa* (d), *Cenchrus cillaris* (d), *cymbopogon caesius* (d), *Cynodon incompletus* (d), *Digitaria eriantha* (d), *Era grostis curvula* (d), *E. lehmanniana* (d), *Heteropogon con tortus* (d), *Setaria lindenbergiana* (d), *Themeda tniandra* (d), *Tragus koelenioides* (d), *Cymbopogon pospischilii, Enneapogon scoparius, Era grostis chloromelas, E. obtusa, Eustachys paspaloides, Fingerhuthia africana, Hyparrhenia hirta, Sporobolus fimbriatus.*

Herbs: *Convolvulus sagittatus, Dianthus caespitosus* subsp. *caespitosus, Gazania krebsiana* subsp. *krebsiana, Hibiscus pusillus, Indigofera alternans, I. rhytidocarpa, Lepidium africanum* subsp. *afnicanum, Pollichia campestris.*

Herbaceous C limber: *Argyroloblum lanceolatum.*

Geophytic Herbs: *Albuca setosa, Asplenium corda tum, Chelianthes bergiana, c. eckloniana, Freesia andersoniae, Haeman thus humilis* subsp. *humilis, Oxalis depressa, Pellaea calomelanos.*

Succulent Herbs: Aloe *grandidentata, Crassula nudicaulis, Duvalia caespitosa, Euphorbia pulvinata, Huemia piersii, Stapelia grandiflora, S. olivacea, Triden tea geminiflora.*

Endemic Taxa Small Tree: *Cussonia* sp. nov. *(Ri. du Preez 3666* BLFU).

Succulent Shrubs: *Euphorbia crassipes, Neohenricia sibbettii, N. spiculata.*

Conservation Least threatened because largely excluded from intensive agricultural activities. Target 28%. About 5% statutorily conserved in the Rolfontein, Tussen Die Riviere, Oviston, Gariep Dam, Caledon and Kalkfontein Dam Nature Reserves. In addition a small patch is also protected in the private Vulture Conservation Area. About 3% of the area has been lost through building of dams (Bethulie, Egmont, Gariep, Kalkfontein, Vanderkloof and Welbedacht Dams). Erosion moderate (68%), high (20%) and low (10%).

Remarks The diversity of the shrub component is lower than in the Gm 5 Basotho Montane Shrubland—a similar shrubland unit occurring on the Drakensberg foothills. The density of shrubs marking the slopes of the koppies decreases along a northeast-southwest gradient. On the southern edges of the distribution area of this unit, shrubs retreat to drainage lines and onto the base of dolerite caps, while the slopes themselves remain covered by dwarf shrublands of the NKu 4 Eastern Upper Karoo. In the northeastern areas which receive a higher rainfall, the sheltered sites have larger trees such as *Rhus lancea* and *Celtis africana.*

APPENDIX C

Observed avifauna

February 2011
Report No. 1280012800-10444-21

Golder Associates

Roberts No.	Common Name	Biological Name	Red Data
102	Goose Egyptian	*Alopochen aegyptiacus*	
152	Buzzard Jackal	*Buteo rufofuscus*	
181	KestrelRock	*Falcotin nunculus*	
203	Guineafowl Helmeted	*Numida meleagris*	
230	Bustard Kori	*Ardeotis kori*	VU
401	Owl Spotted Eagle	*Bubo africanus*	
426	Mousebird Redfaced	*Urocolius indicus*	
438	Bee-eater Eurasian	*Merops apiaster*	
494	Lark Rufousnaped	*Mirafra africana*	
497	Lark Fawncoloured	*Mirafra africanoides*	
507	Lark Redcapped	*Calandrella cinerea*	
518	Swallow Eurasian	*Hirundo rustica*	
526	Swallow Greater Striped	*Hirundo cucullata*	
589	Chat Familiar	*Cercomela familiaris*	
595	Chat Anteating	*Myrmecocichla formicivora*	
601	Robin Cape	*Cossypha caffra*	
615	Robin Karoo	*Cercotrichas paena*	
635	Warbler Cape Reed	*Acrocephalus gracilirostris*	
638	Warbler African Sedge	*Bradypterus baboecala*	
664	Cisticola Fantailed	*Cisticola juncidis*	
665	Cisticola Desert	*Cisticola aridulus*	
677	Cisticola Levaillant's	*Cisticola tinniens*	
711	Wagtail African Pied	*Motacilla aguimp*	
732	Shrike Fiscal	*Lanius collaris*	
762	Starling Pied	*Lamprotornis australis*	
803	Sparrow Cape	*Passer melanurus*	
804	Sparrow Southern Greyheaded	*Passer diffusus*	
814	Weaver Masked	*Ploceusvelatus*	
824	Bishop Red	*Euplectes orix*	
826	Bishop Golden	*Euplectes afer*	

The relevant IUCN status categories are:

Critically Endangered (CR)

Endangered (EN)

Vulnerable (VU)

Near Threatened (NT)

Data Deficient (DD)

Least Concern (LC)

All species without a category are shown as Not Listed (NL)

Shaded species indicate species recorded within the study area

APPENDIX D

Blue Crane Description

February 2011
Report No. 1280012800-10444-21

Golder Associates

Blue Crane (Grus paradisea)

Red List Category: Vulnerable

This species has declined rapidly, largely owing to direct poisoning, power-line collisions and loss of its grassland breeding habitat owing to afforestation, mining, agriculture and development. It is therefore listed as Vulnerable. Although probably stable at present, the population could easily decline again unless appropriate conservation measures are implemented. Evidence of continued population stability or increases may qualify the species for downlisting to Near Threatened in due course.

Range Description: *Grus paradisea* is near-endemic to South Africa, with small breeding populations also in northern Namibia (c.60 birds at Etosha, isolated and rapidly declining) and western Swaziland (c.12 birds). In South Africa, numbers in the south Western Cape have increased as the species has expanded into agricultural areas but, overall, the national population has fallen by half since the 1970s, with dramatic declines in many former strongholds, e.g. of up to 80% in Mpumalanga, KwaZulu-Natal, Free State and Eastern Cape during the 1980s. The latest population estimate is of c. 25,700 individuals.

Population: The population has been estimated at over 25,580 individuals (Beilfuss et al. 2007), with a minimum of 25,520 in South Africa (McCann et al. 2007).

Population Trend: Decreasing

Habitat and Ecology: It inhabits short, dry, natural grasslands, pastures, cropland and fallow fields, only occasionally using wetlands1. Most breeding is concentrated in the period September-January3.

Major Threat(s): The main factors behind its drastic population decline since the 1970s are widespread poisoning on agricultural land (both intentional and accidental) and the commercial afforestation of large tracts of its grassland nesting habitat. Other major threats include collision with power-lines and fences, and illegal capture of fledglings (for pets or food), while domestic-dog predation and chicks drowning in water-troughs are also problems. Prolonged dry spells are suspected to be the cause of the decline in Namibia.

Conservation Actions: Conservation measures have expanded in scale since the mid-1980s, including efforts to mitigate powerline collisions, the adoption of stricter legal protection, local and national surveys in South Africa, increasing research on the species' biology and ecology, habitat protection and management programmes (especially on private land), establishment of local conservation organisations, and the development of educational facilities, programmes and publications.

APPENDIX E

Mountain Zebra Description

February 2011
Report No. 1280012800-10444-21

Golder Associates

Mountain Zebra (*Equus zebra*)

The range of the Mountain Zebra extends across the Central Precinct (), but this species is not free ranging and is restricted in distribution to formally protected areas and private game ranches.

Red List Category: Vulnerable

Listed as Vulnerable as the total population is currently estimated at ca. 9,000 mature individuals, and could be subject to a decline exceeding 10% over the course of the coming 27 years, largely driven by annual harvesting of the Hartmann's Mountain Zebra population. At present, there is limited information available on the population trend of Hartmann's Mountain Zebras, but there is some evidence to suggest that they may well be declining. With the availability of further information on trends from parks and private lands, the species may need reassessment.

Range Description: Historically, Mountain Zebras occurred from the southern parts of South Africa through Namibia and into extreme south-western Angola. Two subspecies are recognized: Cape Mountain Zebras (*E. z. zebra*) were widely distributed along mountain ranges forming the southern and western edge of the of the central plateau of the Eastern Cape and Western Cape provinces of South Africa, from the Amatola Mountains in the Cathcart District westward and northward to the Kamiesberg in Namaqualand in the Northern Cape; Hartmann's Mountain Zebras (*E. z. hartmannae*) occur in the mountainous transition zone between the Namib Desert and the central plateau in Namibia, with a marginal extension into south-western Angola). Novellie et al. (2002) postulate that the ranges of the two subspecies were separated by an area devoid of mountainous habitat between the northernmost point of the Cedarberg and Bokkeveldberg ranges, and the southernmost point of the Kamiesberg range.

Today, surviving natural populations of Cape Mountain Zebra occur only in Mountain Zebra National Park, Gamka Mountain Reserve, and the Kamanassie mountains. Populations have been reintroduced to various parts of their former range, including Karoo National Park, De Hoop Nature Reserve, Karoo Nature Reserve (recently proclaimed as the Camdeboo National Park), Commando Drift Nature Reserve, Baviaanskloof Wilderness Area, Tsolwana Nature Reserve. and Gariep Dam Nature Reserve.

Population: In 1998, the number of Cape Mountain Zebras had increased from <100 animals in the 1950s to about 1,200 individuals, with the largest population (reintroduced), estimated to number 250 in 1998, in the Karoo National Park. The average annual rate of increase of the entire Cape Mountain Zebra population from 1985 to 1995 was 8.6%, and from 1995 to 1998, 9.6%). From 1998 to 2006 there has been a steady increase in the populations of Cape Mountain Zebras from 1003 to 1389 in National Parks and Provincial Nature reserves. In 1998, there were approximately 165 Cape Mountain Zebra on private lands; more recent figures are not available. Hence, the Cape Mountain Zebra population in South Africa has been steadily increasing since the 1980s. The current population size is estimated to be more than 1,500 individuals (ca. 500 mature).

In 1998, the Hartmann's Mountain Zebras population was estimated to number about 25,000, or approximately 8,300 mature individuals (Novellie et al. 2002). Limited data from Namibia indicates that populations are increasing on communal lands in the north-western part of the country (G. Stuart-Hill pers. comm. 2008); from 2000 to 2006, numbers have increased from 6 to 27 individuals observed per 100 km of road surveyed. However, there is no information on the status of populations of Hartmann's Mountain Zebra in the protected, private and communal areas in the rest of Namibia (and see Major Threats).

Population Trend: Unknown

Habitat and Ecology: Mountain Zebra inhabit rugged, broken mountainous and escarpment areas up to around 2,000 m with a rich diversity of grass species and perennial water sources (Penzhorn in press). They are predominantly grazers, only browsing if forced to do so. The typical social structure is one of small harems comprising an adult stallion and one to three (maximum five) mares and their dependent foals; non-breeding groups consist primarily of bachelors, but sometimes include young fillies (Penzhorn in press).

Major Threat(s): Cape Mountain Zebra were once extensively hunted for their skins, because they competed with livestock for grazing, and allegedly because they broke fences (Penzhorn 1988). Today, however, the greatest threat to the Cape subspecies may stem from the risk of crossing with Hartmann's Mountain Zebra, which are introduced to the Eastern and Western Cape.

Conservation Actions: *E. z. zebra* is listed on CITES Appendix I; E. z. hartmannae is listed on CITES Appendix II. Over 90% of the current total population of 1,389 Cape Mountain Zebras are derived from animals relocated from the Mountain Zebra National Park. The management of the Cape Mountain Zebra metapopulation requires the mixing of at least some animals from the three relict populations (MZNP, Gamkaberg, and Kamanassie), all of which are genetically depauperate, although this has been hampered by the relatively slow growth of the Kamanassie population.

APPENDIX F

Riverine Rabbit Description

February 2011
Report No. 1280012800-10444-21

Golder Associates

Riverine Rabbit (*Bunolagus monticularis*)

The Riverine Rabbit is one of the most endangered species in Africa and occurs in a small distribution range in the Karoo (?).The likelihood of occurrence of Riverine Rabbit in the Central Precinct is high and areas such as the Koopmans Graft area will need to be carefully considered in the next phase of the project. Areas likely to host this species are riparian areas especially those with the following characteristics:

- Occur in the central Karoo region;
- Are seasonal;
- Have large, alluvial floodplain with shallow slopes;
- Have dense riverine vegetation (scrub);
- Have scrub of 0.5 - 1 m (1.6 - 3.2') in height; and
- Have soil types that allow stable burrows to be constructed. *(*Stuart & Stuart 1996*)*.

Red List Category: Critically Endangered

No subpopulation is estimated to contain more than 50 individuals, and these subpopulations appear to be isolated due to anthropogenic barriers to dispersal. Quantitative analysis using VORTEX 3.1 showed that the probability of extinction in the wild was more than 50% within the next 100 years.

Range Description: This species is endemic to the central Karoo region of South Africa. The extent of occurrence is 101-5,000 km² and area of occupancy is 11-500 km².

Population: There are less than 90% of mature individuals in one subpopulation. There are 10 subpopulations. There has been a rapid decline of population due to loss of 50-60% of habitat in the past 70 years, this decline has been arrested due to a decrease in cultivation and public awareness and establishment of conservancies. The current population is estimated at less than 250 breeding pairs and is declining. It is estimated that over the last 70 years the population has declined by 60% or more. Population decline of 10% or more is predicted to occur between 2002 and 2022. The population is fragmented, with no subpopulation containing more than 50 individuals. Population densities were estimated at 0.064-0.166/ha.

Population Trend: Decreasing

Habitat and Ecology: The Riverine Rabbit inhabits dense riparian growth along the seasonal rivers in the central Karoo (Nama-Karoo - shrubland). Occurs specifically in riverine vegetation on alluvial soils adjacent to seasonal rivers. The habitat is highly fragmented and transformed. Studies show the habitat to be 67% fragmented in certain areas that can be considered representative of the entire distribution.

Generation length for this species is two years. This species has a single litter per year with 1-2 young per litter. Reproductive periodicity occurs from August through May. Gestation time is 35-36 days. Longevity in captivity is five years. Home range is 12 ha. Total length ranges from 33.7-47.0 cm.

Major Threat(s): Loss and degradation of habitat are the main threats to the species. Over the last century, 50-80% of habitat has been lost as a result of cultivation (mostly in the past) and livestock farming (ongoing). Other threats to the species include hunting (the rabbit is hunted for sport and by farm workers), and accidental mortality in traps set for pest animals on farmlands.

Conservation Actions: *Bunolagus monticularis* is listed as Endangered in the 1986 South African National Red Data Book, and there is a genetic study of the species underway. At the CBSG CAMP South Africa workshop, conservation actions recommended included further research into the life history of this species, management of habitat, wild population management, limiting factors, captive breeding/cultivation, and increased public awareness. The captive breeding/cultivation recommendations include plans for species recovery, education, reintroduction, research, and a management plan workshop. There is currently a coordinated species management program in South Africa.

APPENDIX G

Karoo Rock Sengi

February 2011
Report No. 1280012800-10444-21

Golder Associates

Karoo Rock Sengi (*Elephantulus pilicaudus*)

Red List Category: Data Deficient

The Karoo Rock Sengi has recently been described as a sister species of the Cape Rock Sengi, *Elephantulus edwardii*. Specific information on the abundance, distribution, and population status of the new species is lacking and although no major threats are currently known, it is tentatively listed as Data Deficient pending the availability of further study and survey work.

Range Description: The new species is endemic to South Africa in the Northern Cape Province and the north-western edge of Western Cape Province. The species therefore appears limited to the Nama-Karoo vegetation biome in the south-central semi-arid Karoo of South Africa. The Nama-Karoo is subdivided into Bushmanland and the Upper and Lower Karoo bioregion vegetational units (Mucina and Rutherford 2006). Based on genetic evidence, *E. pilicaudus* is divided into two clades. Specimens from the Upper Karoo bioregion have a different genetic profile than those from the Lower Karoo bioregion. Because there are only five known locations where the new species occurs, the distribution is not well understood, although it appears to be highly restricted. It is possible that the distributions of the Cape Rock Sengi (*E. edwardii*) and the Western Rock Sengi (*E. rupestris*) do not overlap with E. pilicaudus. Within the range of the new species, it is not likely to be continuously distributed because its boulder and rock habitats are highly fragmented. All known locations are >1,300 m above sea level.

Population: The abundance and population size is unknown. Despite numerous field excursions in the region, only 17 specimens of the new species from five locations in the Nama Karoo are known (three live trapped by Hannelie Smit; two trapped by Galen Rathbun, and 12 museum specimens housed in South African museums). In October 2008, a farm near Calvinia in the Northern Cape Province of South Africa, where three live specimens were trapped in September 2006, was revisited by H. Smit and an effort to trap additional live specimens was unsuccessful. This reinforces the evidence of a species with a low abundance.

Population Trend: Unknown

Habitat and Ecology: This species is confined to rocky or boulder-strewn habitats against mountain slopes or on ridges. Based on the five locations where it has been trapped, the species may have similar ecology as its sister species the Cape Rock Sengi (*E. edwardii*), and the boulder- and rock-dwelling Western Rock Sengi (*E. rupestris*).

Major Threat(s): The species occurs in an area of ongoing livestock farming, which poses no direct threat to the species. Because it occupies rocky and boulder habitats that are not suitable for most agricultural or urban development, there are no known threats to the Karoo Rock Sengi.

Conservation Actions: Concerted efforts should be made to assess the relative abundance of the new species and further document its apparent limited distribution. It is unknown whether the species occurs in any protected areas other than the Karoo National Park, Beaufort-West. The species is limited to a region of local endemism and shares a distribution with other Karoo endemic mammals, such as *Bunolagus monticularis* and *Aethomys grantii*, which may be an important consideration in identifying and establishing additional protected areas in the region.

APPENDIX H

White-tailed Mouse Description

White-tailed Mouse (*Mastomys albicaudatus*)

Red List Category: Endangered

Listed as Endangered, although this species currently occurs across a relatively wide area, its habitat is fragmented and it is declining as a result of grazing and agricultural pressures. It is estimated that 51-80% of suitable habitat for the species has been lost over the last 40 years, and over 50% of the remaining habitat is expected to be lost over the next ten years if current agricultural practices continue. With this rate of habitat loss, it is projected that more than 50% of the current population will be lost over the next ten years.

Range Description: This species is relatively widespread across South Africa and Lesotho. There are no museum records from Swaziland, where extensive trapping for the last 10 years has not detected the species suggesting that it does not occur in this country.

Population: The current size of the population is not known, however, the low capture rate experienced during surveys suggest that numbers are extremely low. The population is expected to further decrease as a result of habitat loss over the next decade.

Population Trend: Decreasing

Habitat and Ecology: The species occurs in shrubland and grassland areas. A major requirement of the species is black loam with good vegetation cover. They breed once or twice a year and live up to 6 years.

Major Threat(s): The main threat to the species is habitat loss as a result of agriculture. Grazing pressure is also contributing to the loss of habitat for this species.

Conservation Actions: Conservation actions needed for this species include further survey work, research into the life history of the species, PHVA analysis, and increased public awareness of the species is recommended. The range of the species includes a few protected areas.

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Project done on behalf of
Golder Associates Africa (Pty) Ltd

AIR QUALITY TECHNICAL ASSESSMENT: REPORT IN SUPPORT OF THE EMP FOR THE SOUTH WESTERN KAROO BASIN GAS EXPLORATION APPLICATION PROJECT – CENTRAL PRECINCT

Report No.: APP/10/GAA-11 Rev 0

DATE: FEBRUARY 2011

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REPORT DETAILS

Reference	APP/10/GA-11
Status	Revision 0
Report Title	Air Quality Technical Assessment: Report in Support of the EMP for the South Western Karoo Basin Gas Exploration Application Project – Central Precinct
Date Submitted	February 2011
Client	Golder Associates Africa (Pty) Ltd
Prepared by	Lucian Burger PhD (Natal), MSc Eng (Chem), BSc Eng (Chem)
Notice	Airshed Planning Professionals (Pty) Ltd is a consulting company located in Midrand, South Africa, specialising in all aspects of air quality, ranging from nearby neighborhood concerns to regional air pollution impacts. The company originated in 1990 as Environmental Management Services, which amalgamated with its sister company, Matrix Environmental Consultants, in 2003.
Declaration	Airshed is an independent consulting firm with no interest in the project other than to fulfil the contract between the client and the consultant for delivery of specialised services as stipulated in the terms of reference.
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EXECUTIVE SUMMARY

Shell Exploration Company B.V., a registered company of Royal Dutch Shell plc (Shell), has applied to the Petroleum Agency of South Africa (PASA) seeking the award of Exploration Rights to undertake shale gas exploration activities in the South Western Karoo Basin, South Africa. This document relates to the Exploration Right application referred to as the Central Precinct, which intersects the Eastern, Western and Northern Cape Provinces, and covers the Cacadu, Central Karoo, Chris Hani, and Pixley ka Seme District Municipalities.

Airshed Planning Professionals (Pty) Ltd was tasked with conducting an air quality assessment for the proposed gas exploration as an integral part of the overall Environmental Management Plan (EMP), which is being completed by Golder Associates Africa (Pty) Ltd.

METHODOLOGY

The main objective of this study was to compile the necessary air quality and meteorological information for input into the EMP. This study included the description of the current atmospheric conditions in the study area, legal requirements pertaining to air pollution, predicted air impacts, mitigation and management measures, and key questions that would need to be addressed in the detailed environmental impact assessment (EIA).

Historical records of air quality, meteorological parameters and climatological behaviour were sourced and summarised to produce a succinct account of the current (baseline) conditions.

All significant sources of air emissions and associated air pollutants were identified and discussed for their significance.

BASELINE CONDITIONS

The study area has a low level of industrial activity. The only identified sources of significant air pollution are the current farming activities. These emissions are mainly airborne particulates. It is therefore expected that air concentrations of sulphur dioxide and nitrogen dioxide would be 5 parts per billion (ppb) or less. Due to agricultural activities, the daily average inhalable particulate concentrations would be about 20 $\mu g/m^3$ or less. Air concentrations of volatile organic compounds, such as benzene are expected to be very low (less than 2 ppb for benzene and less than 10 $\mu g/m^3$ for combined volatile organic compounds).

The South African Weather Services (SAWS) automatic weather station at Beaufort West (identification number 0092081 5) has been identified to provide meteorological data at the level of detail which is required to use for atmospheric dispersion modelling and general climate statistics. It should be noted that Beaufort West falls just outside the study area towards the southwest. The effect of the topographical barrier that shelters the study area towards the north would not be shown by this figure. Instead, it is expected that the southerly wind components may be less pronounced. Nonetheless, it is believed that the prevailing easterly wind would be similar to the conditions in the study area. Furthermore,

the strong westerly winds are also expected to occur in the study area. Low occurrence of calm wind conditions are also illustrated with these observations.

The region is in a dry area with the automatic weather station at Beaufort West receiving only 223 mm per annum on average. A number of other rainfall stations exist in the study area. The mean annual precipitation ranges from 218 mm (Bakensrug, 0093314_W) to 411 mm (Quaggasdrift, 0095006_W).

It is not expected that the site will experience a hurricane, or at least there is a very low probability. Similarly, the estimated frequency of a tornado strike risk is about 1×10^{-5} per year per km^2 to the east, and becomes less moving towards the west of the study area. The average number of days with hail in the study area is 1.7 per year. It is estimated that the study area experiences between 1 (western portion) and 5 (north-eastern portion) lightning flashes per year per km^2.

Recommended Baseline Monitoring Programme

It is recommended that the air quality monitoring network be established prior to construction to confirm current air quality. The pollutants to include in the monitoring network include:

- Particulate monitoring (PM10 and fallout)
- Sulphur dioxide
- Nitrogen dioxide

Although its significance would only be established during the EIA, it is also suggested to include measurements of volatile organic compounds and hydrogen sulphide in the campaign.

It is suggested that the sampling technique for the gaseous pollutants could initially be based on the technique of passive diffusive sampling. On completion of the detailed environmental technical assessment, a better level of understanding of the magnitude of the anticipated air concentrations would guide whether more sophisticated instruments would be required during the construction and exploration phases. The techniques outlined in the South African National Standards, SANS 1929:2004 would then be recommended

Particulate monitoring would be required for both airborne concentrations and fallout dust.

Although monitors should be located in areas that are expected to result in elevated air concentrations, monitors should also be located in sensitive areas, e.g. at the residential boundary closest to the exploration site.

TECHNICAL ASSESSMENT

Air pollution emissions are expected to occur during site preparation, exploration drilling, hydraulic fracturing and decommissioning.

Site Preparation

Potential Air Emissions

The air pollution generated during site preparation would be the same as for any other general construction activities, with the main air pollutant being airborne dust. The various activities during site preparation require disturbing the soil to some degree through the use of construction machinery. Depending on the soil type, this could generate significant amounts of fugitive dust during the limited period of site preparation.

In addition, combustion gases (sulphur dioxide, oxides of nitrogen, carbon monoxide, 1, 3-butadiene, diesel particulate matter) will be emitted from vehicle exhausts.

As these vehicles may be also be fuelled on site, the potential to emit volatile organic compounds exists.

Predicted Impact

The air pollution impact during site preparation is expected to be *Moderate* without mitigation measures. Following mitigation, these impacts can be reduced to *Low* significance. The technical assessment ratings are summarised in Table A.

Table A: Environmental technical assessment matrix – Site Preparation

POTENTIAL ENVIRONMENTAL IMPACT: SITE PREPARATION	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Various activities during site preparation require disturbing the soil to some degree through the use of construction machinery. Fugitive dust will be released as well as exhaust emissions	8	1	1	5	56	Moderate	4	1	1	5	28	Low

Note: M=magnitude, D=duration, S=scale, P=probability and SP=significant point.

Mitigation Measures

- It is often customary to regulate particulate emissions from haul roads employing a watering programme. However, the potential restrictive use of water may prohibit this practice. Instead chemical suppressants or tarring could be considered. The practicality of surface treatment methods need to be investigated during the EIA phase.
- Additional mitigation measures include reduced vehicle speeds and coverage of haul truck loads.

- Vegetation is to only be removed when soil stripping is required. These areas should be limited to include only those areas required for development, hereby reducing the surface area exposed to wind erosion. Adequate demarcation of these areas should be undertaken.
- The length of time where open areas are exposed should be restricted. Construction of infrastructure should not be delayed after land has been cleared and topsoil removed.
- It is also important to minimise exposed areas prone to wind erosion and to re-vegetate as soon as practically possible.
- Removed topsoil should be stored under cover to prevent wind erosion, if it is to be used for restoration, otherwise re-vegetate the surface as soon as possible.
- Control options pertaining to topsoil removal, loading and dumping are generally limited to wet suppression. The options exist in scheduling this activity to coincide with periods when soil moisture can be expected to be optimal.
- Dust suppression methods should be where logistically possible, implemented at all areas that may / are exposed for long periods of time.

Recommended Monitoring

Particulate air quality monitoring, including both air concentrations of PM_{10} and fallout must continue during the site preparation period.

Exploration Drilling and Hydraulic Fracturing

Potential Air Emissions

The air emissions expected to occur during exploration include the following operations:

- Transportation
- Compressors
- Well flaring
- Power generators
- Drilling rig
- Open air fluid impoundments

The expected pollutants emanating from these different activities are summarised in Table B.

Table B: Summary of potential sources of air emissions

Air Pollutant	Roads	Vehicle	Engines	Flare	Impoundments	Fugitives
Particulate Matter	X	X	X	X		
Sulphur dioxide		X	X	X		
Oxides of nitrogen		X	X	X		
Carbon monoxide		X	X	X		
Hydrogen sulphide[a]				X[b]		X

Air Pollutant	Roads	Vehicle	Engines	Flare	Impoundments	Fugitives
VOCs		X	X	X	X	X
PAHs		X	X	X		
Methane					X	X

Notes: [(a)] – hydrogen sulphide emissions will occur if there is sour gas. Early explorations done by Soekor did not encounter hydrogen sulphide (not from the drilling reports, nor core analyses). The gas composition that was measured in the past was a mix of mainly Methane (92%) , Ethane (6%) and higher hydrocarbon chains (2%) (Rowsell, D.M. and De Swardt, A.M.J., 1976, Diagenesis in Cape and Karroo sediments, South Africa, and its bearing on their hydrocarbon potential. Transactions of the Geological Society of South Africa 79 (1), 81-129)
(b) – in the unlikely event of an extinguished flare and the well not yet isolated.

Predicted Impact

The air pollution impact during exploration drilling and hydraulic fracturing is expected to be *Moderate* without mitigation measures.
Following mitigation, these impacts can be reduced to *Low* significance. The technical assessment ratings are summarised in Table C.

Table C: Environmental technical assessment matrix – Exploration Drilling and Hydraulic Fracturing

POTENTIAL ENVIRONMENTAL IMPACT: EXPLORATION DRILLING AND HYDRAULIC FRACTURING	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Routine emissions are expected from power generators and compressors. Fugitive emissions may occur at drill rig and open air fluid impoundments. Gas may be flared.	6	2	2	4	42	Moderate	4	2	2	4	28	Low

Note: M=magnitude, D=duration, S=scale, P=probability and SP=significant point.

Given the current requirements for atmospheric emission licences (AEL), the facility may not need to apply for an AEL. This will be reviewed once all equipment has been sized.

Mitigation Measures

- Mitigate particulate emissions from haul roads by reducing vehicle speed and, if possible, using regular watering. Chemical suppressants or more permanent surface

treatment methods should also be considered. The practicality of surface treatment methods need to be investigated during the EIA phase.

- Use low-sulphur fuel and efficient engines. Engines must be regularly maintained
- Infrared monitoring instrumentation to detect fugitive emissions.
- Minimise surface area if open air impoundments will be used.
- In case of flaring:
    - flare to be located away from receptors (dispersion modeling to be used to assist with the location);
    - use high efficiency burners;
    - in the event that the flare fails, well must be shut to prevent venting of gas directly to air.
- Installation of vapour recovery unit can eliminate most of the VOC emissions and recover valuable natural gas during flow back and well testing

Recommended Monitoring

The pollutants to include in the monitoring network include:

- Particulate monitoring (PM10 and fallout)
- Sulphur dioxide
- Nitrogen dioxide

Although its significance would only be established during the EIA, it is also suggested to include measurements of volatile organic compounds and hydrogen sulphide in the campaign.

Unless these emissions prove to be more significant, the monitoring using passive diffusion sampling methodology would be adequate.

Decommissioning

Potential Air Emissions

Minimal emissions are expected upon closure of the exploration well, and would mainly include particulate emissions during the closure process.

Fugitive particulate matter and VOC emissions may also occur during the rehabilitation of any fluid impoundments.

Predicted Impact

The air pollution impact during decommissioning is expected to be *Low*, as shown in Table D.

Table D: Environmental technical assessment matrix – Decommissioning

POTENTIAL ENVIRONMENTAL IMPACT: DECOMMISSIONING	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Various activities during site closure may disturb the soil to some degree through the use of clean-up machinery. Fugitive dust will be released as well as exhaust emissions	4	1	1	3	20	Low	4	1	1	3	20	Low

Note: M=magnitude, D=duration, S=scale, P=probability and SP=significant point.

Mitigation Measures

- If practical, regular watering of unpaved haul roads;
- Reduce vehicle speeds;
- Minimise exposed areas prone to wind erosion; and
- Cover haul truck loads.

Recommended Monitoring

Continuation of particulate air quality monitoring, including both air concentrations of PM_{10} and fallout must continue during the site preparation period.

KEY QUESTIONS THAT NEED TO BE ADDRESSED IN THE EIA

The next phase of work will require that a full environmental impact assessment (EIA) be undertaken. In order to assess the impacts on air quality, the following key questions will need to be answered:

- What is the current air quality at each of the selected drilling sites?
- What will the impacts (quantified) on air quality be due to the site preparation, exploration drilling, hydraulic fracturing and decommissioning activities?
- What mitigation measures can be implemented to reduce the impacts to acceptable levels?

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1. INTRODUCTION

Shell Exploration Company B.V., a registered company of Royal Dutch Shell plc (Shell), has applied to the Petroleum Agency of South Africa (PASA) seeking the award of Exploration Rights to undertake shale gas exploration activities in the South Western Karoo Basin, South Africa. This document relates to the Exploration Right application referred to as the Central Precinct, which intersects the Eastern, Western and Northern Cape Provinces, and covers the Cacadu, Central Karoo, Chris Hani, and Pixley ka Seme District Municipalities (Figure 1-1). The study area specific to this project is delineated with a purple line, and includes towns such as Victoria West and Murraysburg.

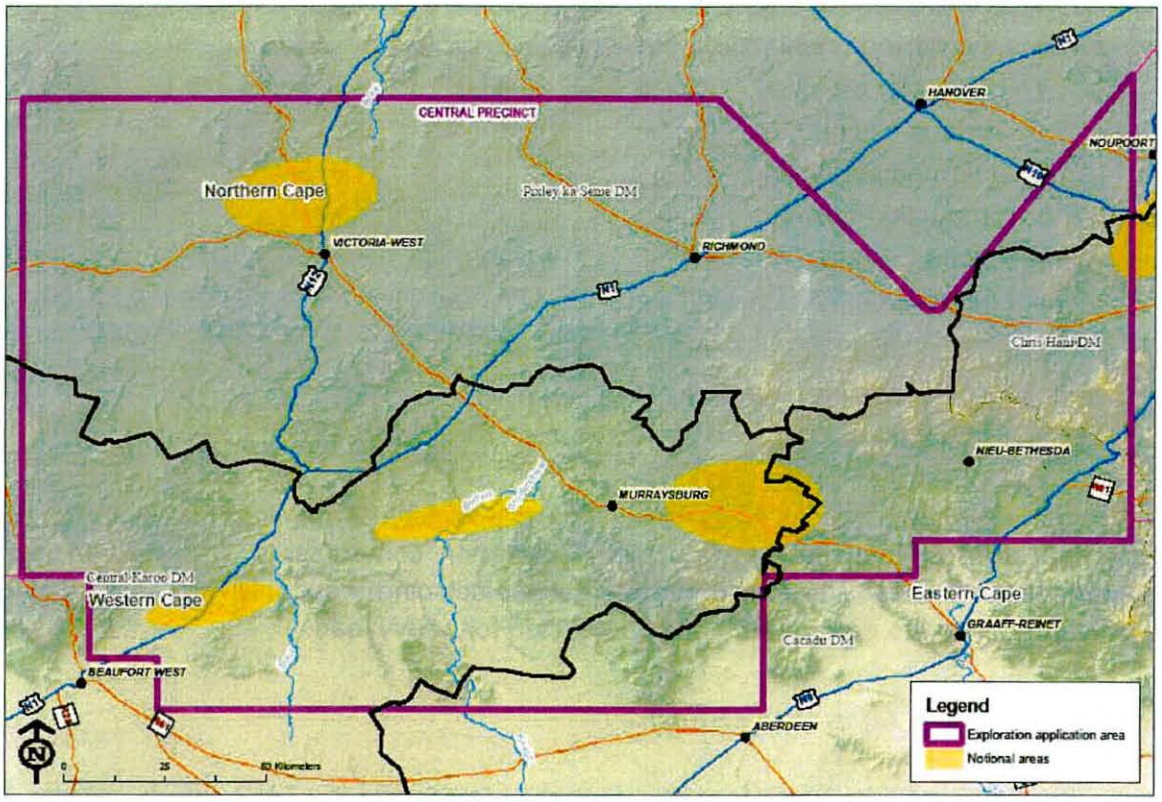

Figure 1-1: Project overview (purple line) and adjacent exploration rights applications (red lines)

Airshed Planning Professionals (Pty) Ltd was tasked with conducting an air quality assessment for the proposed gas exploration as an integral part of the overall Environmental Management Plan (EMP), which is being completed by Golder Associates Africa (Pty) Ltd.

1.1. Brief Overview of the Proposed Exploration Application Project

The precise locations within the proposed area where exploration activities may take place have not yet been identified. Figure 1-1 illustrates the possible areas within which suitable well sites may be identified for the proposed exploration drilling activities.
Drilling and completing a gas well consists of several sequential activities, of which the following are typical:

- building the location and installing fluid handling equipment;
- setting up the drilling rig and ancillary equipment;
- drilling the hole;
- running electrical and other instruments in the well (logging the hole);
- running the casing (steel pipe):
    - conductor pipe;
    - surface casing;
    - intermediate casing; and
    - production casing.
- cementing the casing;
- logging the casing;
- removing the drilling rig and ancillary equipment;
- perforating the casing; and
- hydraulic fracturing.

Apart from the drilling rig, other ancillary equipment that may be required for the exploration include haul trucks, water tankers, electricity generator, compressors, fuel storage and a flare. Establishing a well site for drilling operations, including a suitable access road to the site, which may need to be prepared and compacted for heavy load.

1.2. Objectives and Aims of the Study

This study aims to provide the necessary information to compile the EMP, which includes the description of the current atmospheric conditions in the study area, legal requirements pertaining to air pollution, predicted air impacts, mitigation and management measures, and the recommendations for the detailed environmental impact assessment.

1.3. Study Approach / Methodology

Historical records of air quality, meteorological parameters and climatological behaviour were be sourced and summarised to produce a succinct account of the current (baseline) conditions. Since the locations of weather monitoring stations were not necessarily nearby the proposed exploration areas, interpolations and extrapolations were required. The orography of the region is important and major topographical features were identified to determine whether the prevailing meteorological patterns may be altered.

Since the study area is in a relatively underdeveloped area with respect to large industries, the need to establish ambient air quality monitoring networks and campaigns have not been seen. Since no observations of air pollutants could be obtained a general discussion on the expected air pollution levels were provided based on the State of Air Report 2005 issued by the Department of Environmental Affairs (DEA 2009a).

Based on the extent of the spatial difference between the different exploration locations within the study area, the baseline conditions are expected to be applicable to the entire area. Where necessary, recommendations were provided on the implementation of ambient air monitoring equipment prior to the exploration.

Although air pollution emission rates were not quantified in this study, all significant sources of air emissions and associated air pollutants were identified and discussed for their significance.

2. BASELINE DESCRIPTION OF THE STUDY AREA

2.1. Existing Air Quality

The study area has a low level of industrial activity. The only identified sources of significant air pollution are the current farming activities. These emissions are mainly airborne particulates. Commercial activities, albeit relatively small, vehicular exhausts and domestic use of wood and coal in Victoria West, Murraysburg and Beaufort West may result in elevated combustion pollutants such as carbon monoxide, sulphur dioxide, oxides of nitrogen and particulates. The use of solvents and fuel (mainly petrol) evaporation would also result in some volatile organic compounds (VOC) emissions.

Given the relative small sizes of the towns and the main farming types (i.e. sheep and game), it is believed that the impacts from the current air pollution sources would most likely not have any significant contribution to the air pollution expected to occur from the proposed activities.

According to the current understanding of the air quality in South Africa (DEA 2009a), the air concentrations of nitrogen dioxide in rural regions, such as the study area, would range between 0.5 parts per billion (ppb) to 4.5 ppb. Similarly, the expected sulphur dioxide air concentrations would be between 0.5 ppb and 2.5 ppb (DEA 2009a). The DEA (DEA 2009a) recommends a background inhalable particulate concentration of 16.39 $\mu g/m^3$, based on observations made north of Port Elizabeth in the Eastern Cape. Due to the agricultural activities, daily average inhalable particulate concentrations are therefore expected to be about 20 $\mu g/m^3$ or less. Air concentrations of volatile organic compounds, such as benzene are expected to be very low (less than 2 ppb for benzene and less than 10 $\mu g/m^3$ for combined volatile organic compounds) (DEA 2009a).

2.2. Climatology

The climatic changes during the year affect the dispersion potential significantly due to the presence and the prevalence of large scale air mass characteristics. So for instance, persistent inversion conditions during winter periods, especially during the arrival of cold fronts, result in restricted vertical mixing of air contaminants. Depending on the height of release above ground level and the time of day, this could result in high ground level air concentrations. During the night, the worst condition would be for releases near the ground. Under these conditions, elevated plumes would normally only impact at relatively far distances from the point of emission, and the resulting air concentrations may then be relatively low. However, as the sun rises and the Earth's surface heats up, the surface inversion layer erodes from the bottom up, and elevated emissions may become trapped below the lifting inversion (known as *fumigation*), potentially causing high ground level concentration.

South Africa is located in the dry subtropics of the Southern Hemisphere. According to planetary forces as a result of equatorial-polar temperature (pressure) gradients and the rotation of the Earth, the subtropics is dominated by subsidence of air and high pressures in the lower atmosphere, which results in stability and therefore increased prevalence and strengths of inversion conditions during the winter season.

During summer months the South African continent radiates more energy towards the atmosphere than most of the surrounding ocean, meaning that lower pressures and convection will develop over the continent. This coincides with clockwise rotation (see Figure 2-1) which "draws" moist tropical air towards the south by means of a band of clouds extending from the north-west to the south-east. This mechanism, also known as a tropical temperate trough, is the most important reason for the occurrence of summer rain over the eastern parts of South Africa. There are obviously variations in the strength and location of low pressure systems in relation to the surrounding higher pressures in the day-to-day weather of South Africa.

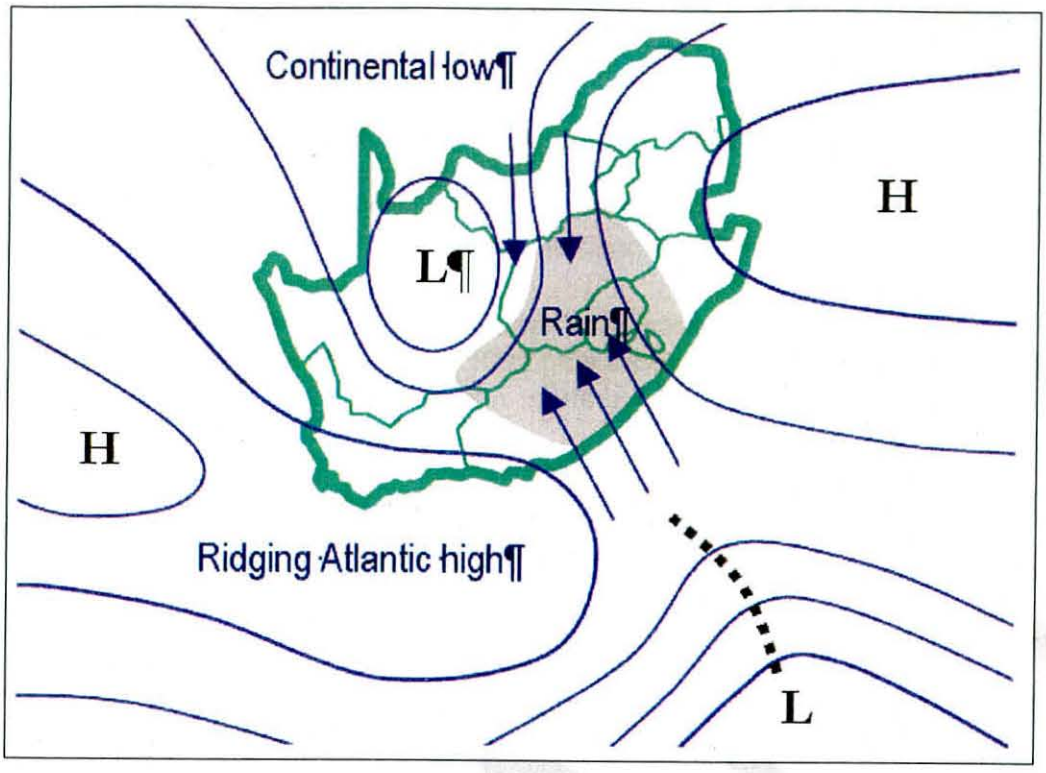

Figure 2-1: Rainfall over South Africa is caused by continental atmospheric pressure disturbances. During summer months continental radiation allow for the formation of clockwise continental lows which draws moist air from the tropics towards the eastern parts of South Africa

Predominantly dry conditions over the interior returns during winter months when radiation from the continent's surface declines and the South African region returns to a state of normally dry conditions. However, the southern coastline of South Africa is just far enough south so that cold air masses from the poles (cold fronts) manage to sweep from west to east over the ocean and adjacent southern coastline of the African continent. During winter months cold fronts might even propagate over the continent, and with the Indian Monsoon, might transfer cold air as far north as Kenya. With enough moisture in the atmosphere, cold fronts might instigate cloud development and rainfall, since the cold heavy air mass serves as an obstacle against which warmer moist air might lift to allow for adiabatic cooling, condensation and eventually rain. It is this process that brings most of the winter rain to the Western Cape.

Cold fronts propagate from west to east over the interior (mostly winter) or southern tip or southern ocean (mostly summer) of South Africa throughout the year. These fronts are normally followed by cold heavy air with high pressure values. When a cold front passes, the pre-frontal high pressure region might link up with the Atlantic High which is normally located to the west of the country over the Atlantic Ocean. On a weather map such conditions are referred to as a ridging high. Ridging highs (or anticyclones) are main reason for onshore air flow along the southern and eastern coast line of South Africa, which might develop in rainfall when topographic lift takes place along the continental escarpment.

2.3. Meteorological Parameters

The following South African Weather Services (SAWS) weather station have been identified to provide meteorological data at the level of detail which is required to use for atmospheric dispersion modelling and general climate statistics:

- Beaufort West (identification number 0092081 5)

Although some these stations have statistical summaries dating back to the 1920's the use of automatic weather stations was only initiated during 2006. This data include hourly average wind speed, wind direction, ambient air temperature, relative humidity, barometric pressure and rainfall.

There are a number of rainfall stations, in addition to this automatic weather station. These are discussed in Section 2.3.3

2.3.1. Ambient Air Temperatures and Relative Humidity

Ambient air temperature is an important parameter when simulating dispersion of plumes. This is particularly important when the plumes are hot, cold or heavier than air. Plume buoyancy relative to the ambient air will determine whether it will rise, fall or remain near neutral with respect to ground level.

Table 2-1 is a summary of historical dry bulb temperature measurements made at Beaufort West. These data were taken from the SAWS summary of 1984 (WB40, 1984). The monthly variation of dry bulb temperatures for 2010 is shown in Table 2-2. The very low temperatures are a clear indication of the extreme cold conditions that can be experienced in the study area.

Table 2-1: Long-term annual average temperature and relative humidity statistics (WB10, 1984)

Site	Dry bulb temperature (°C)					Relative Humidity (%)		
	Daily			Extreme		08h00	14h00	20h00
	Ave	Min	Max	Min	Max			
Beaufort West	25.2	4.7 (July)	32.2 (January)	-5.6	42.0	62	29	39

Table 2-2: Monthly dry bulb temperature statistics for 2010

Month	Beaufort West		
	Minimum (°C)	Average (°C)	Maximum (°C)
Jan	11.3	24.2	39.2
Feb	13.4	24.7	39.4
Mar	10	22.6	36.4
Apr	4.8	18.6	35.9
May	1.5	16.3	28.1
Jun	-0.7	12	27.9

Month	Beaufort West		
	Minimum (°C)	Average (°C)	Maximum (°C)
Jul	0	13.5	27
Aug	0.2	15.8	32.5
Sep	2.7	16.7	35.1
Oct	6.2	17.1	34.2
Nov	9.1	20.9	36.2
Dec	9.7	21	36.8

Although relative humidity plays a relatively minor role during routine atmospheric emissions, it could play a more important role when considering accidental releases of large volumes of natural gas, in the event that it is contained in a gas holder. Depending on the release condition, the ambient air temperature and the relative humidity, such a plume would initially disperse slowly near the ground (passive plume). Fairly high concentration levels can result under such conditions. The monthly variation of relative humidity for 2010 is shown in Table 2-3.

Table 2-3: Monthly relative humidity statistics for 2010

Month	Beaufort West		
	Minimum (°C)	Average (°C)	Maximum (°C)
Jan	8	47.2	94
Feb	6	44	96
Mar	13	51.2	94
Apr	7	49	97
May	7	45	98
Jun	7	47	98
Jul	9	42.6	97
Aug	6	32.6	97
Sep	5	37.3	92
Oct	45	49	97
Nov	3	41.4	87
Dec	9	53	97

2.3.2. Wind Speed and Direction

The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer. Dispersion comprises vertical and horizontal components of motion. The stability of the atmosphere and the depth of the surface-mixing layer define the vertical component. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. Meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer.

Figure 2-2 summarises the wind conditions at Beaufort West. Wind roses comprise 16 spokes, which represent the directions from which winds blew during the period. The colours reflected the different categories of wind speeds; the grey area, for example, representing winds of 1 m/s to 2 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. For the current wind roses, each dotted circle represents a 5% frequency of occurrence. The value given in the centre of the circle described the frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s.

It should be noted that Beaufort West falls just outside the study area towards the southwest. The effect of the topographical barrier that shelters the study area towards the north would not be shown by this figure. Instead, it is expected that the southerly wind components may be less pronounced. Nonetheless, it is believed that the prevailing easterly wind would be similar to the conditions in the study area. Furthermore, the strong westerly winds are also expected to occur in the study area. Low occurrence of calm wind conditions are also illustrated with these observations.

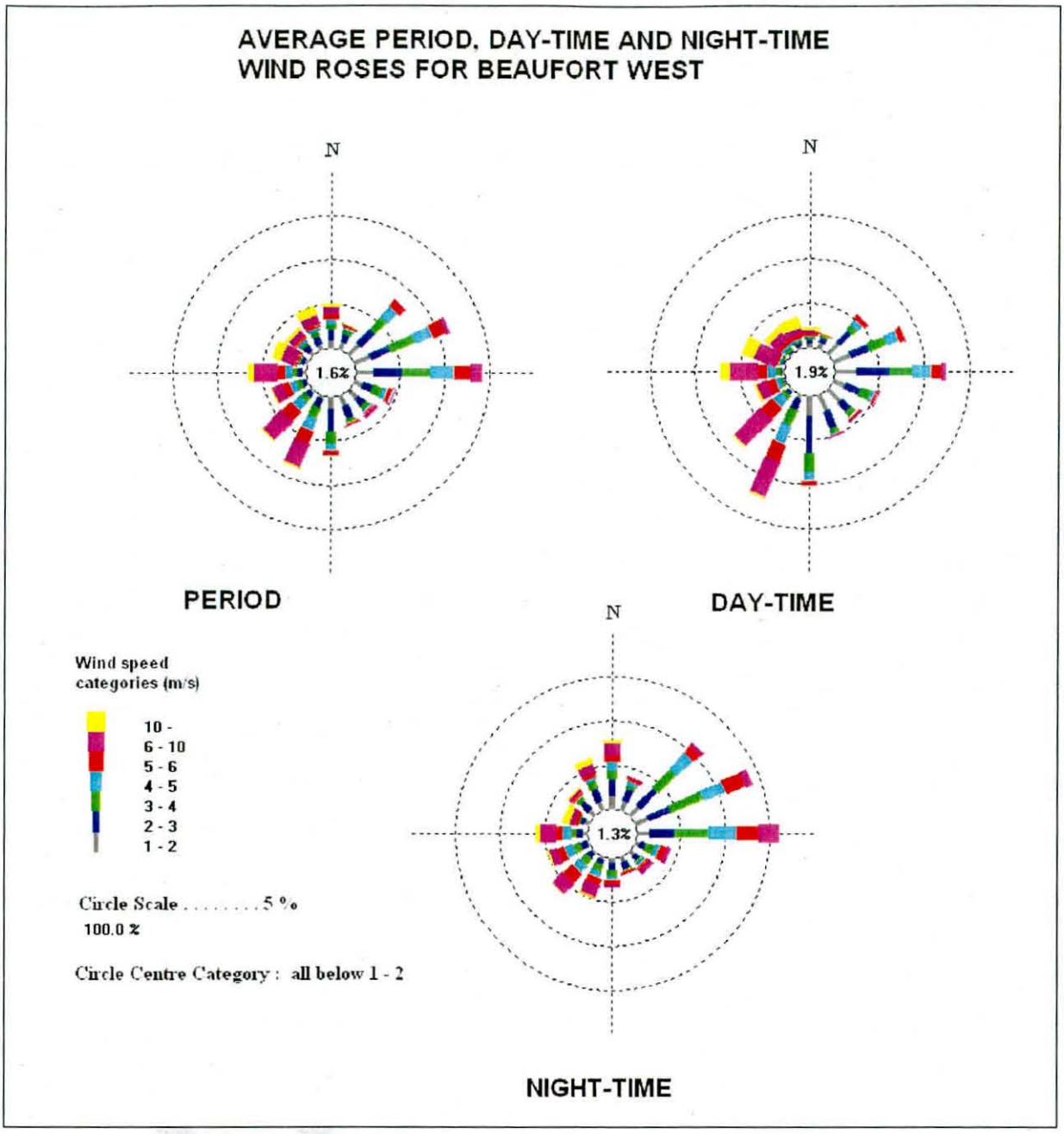

Figure 2-2: Wind roses for Beaufort West

2.3.3. Precipitation

Basic rainfall statistics are summarised in Table 2-4. These data were taken from the SAWS summary of 1984 (WB40, 1984).

The region is clearly in a very dry area. For example, Beaufort West received on average only 223 mm per annum.

Table 2-4: Long-term rainfall statistics and rare meteorological phenomena (WB10, 1984)

Site	Rainfall (mm)				Number of Days			
	Annual Ave	Maximum		No Days >10 mm	Thunder	Hail	Snow	Fog
		24-hour	Month					
Beaufort West	223	97	473	5.8	23.8	1.7	0.5	12.2

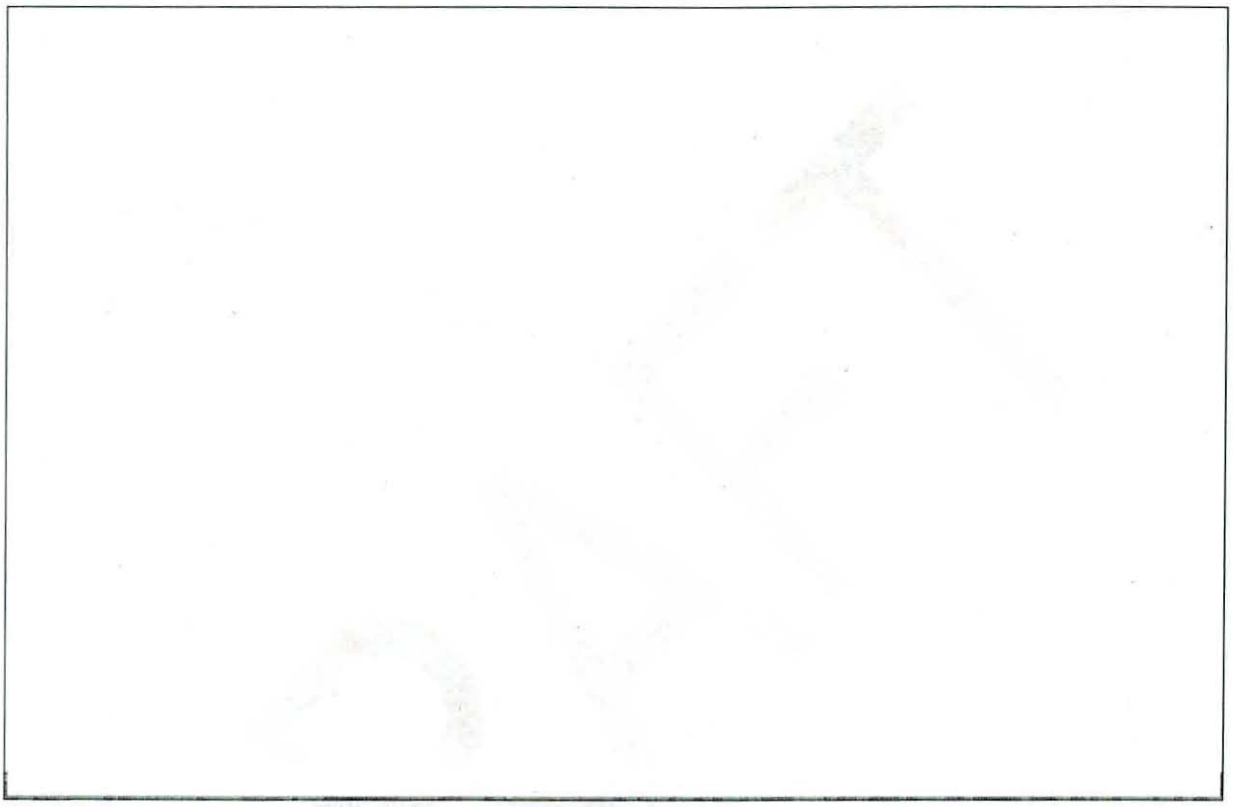

Figure 2-3: Monthly rainfall for 2010 at Beaufort West

The table also includes the occurrences of rare phenomena such as thunder, hail, snow and fog. A relatively high number of days with thunder is observed, whilst snowfalls are not very common.

The monthly variation of rainfall at the Beaufort West station for 2010 is shown in Figure 2-3. Although the pattern displays a typical summer rainfall region, a fair amount of rain occurred during June and July.

A summary of extreme rainfall events and MAP for a number of other observational stations within the proposed exploration area is given in Table 2-5. The daily rainfall data for eight rain gauges with long historical records in the precinct were extracted and analysed (see *Surface Water Technical Report,* Golder Associates 2011). The locations of the rain gauges are shown in Figure 2-4. The data was analysed to determine the rainfall depths for the different recurrence interval 24 hour storms (Smithers and Schulze, 2003) as well as the MAP, minimum, average and maximum monthly rainfall depths. The results of the analysis are given in Table 2-5.

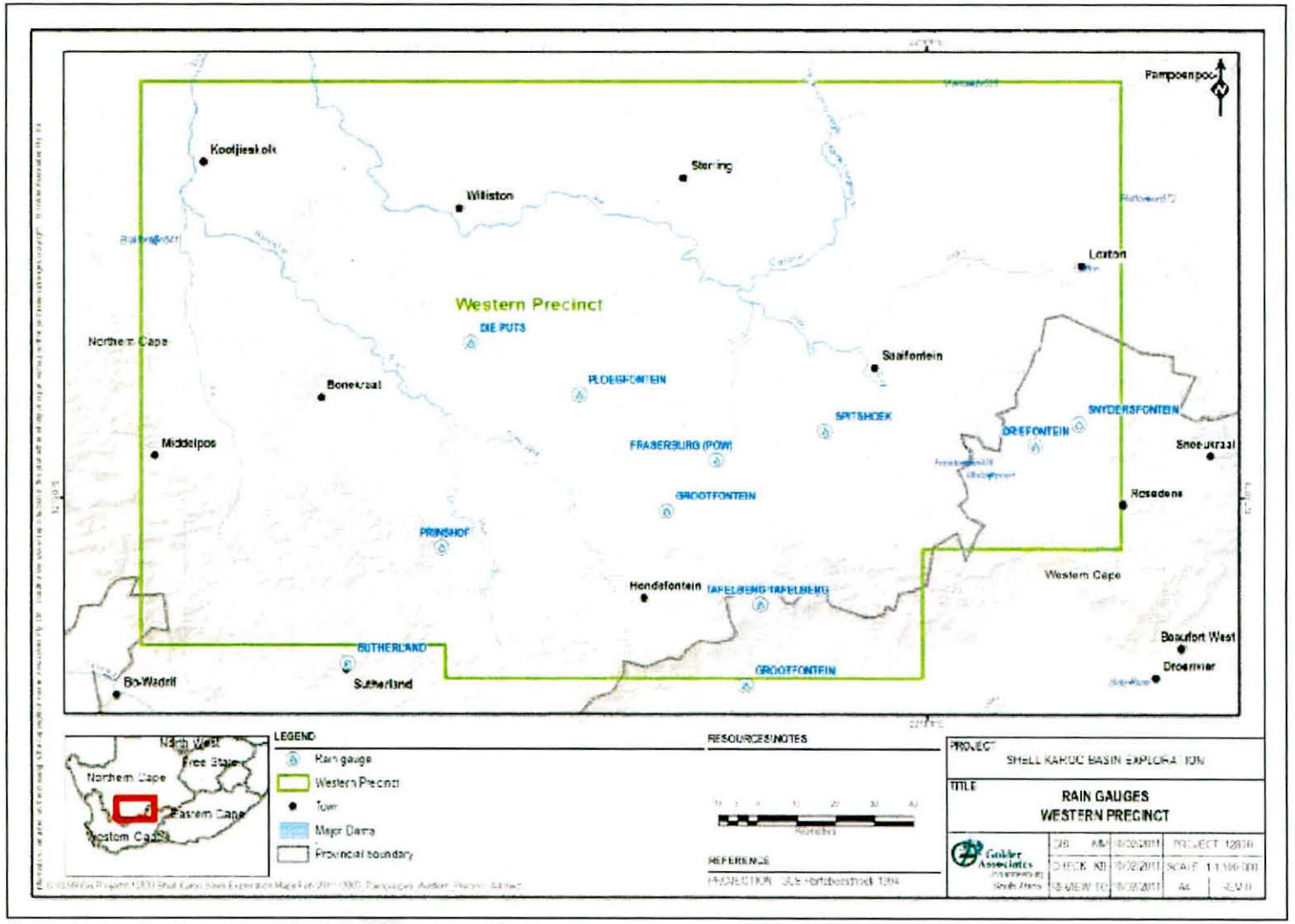

Figure 2-4: Locations of rain gauges in the western precinct

Table 2-5: The mean annual precipitation (MAP) and maximum 24-hour rainfall for a number of return periods within the six exploration areas of the Central Precinct

Rainfall Station	MAP (mm)	Return Period (years)						
		2	5	10	20	50	100	200
Victoria West 1								
Sterling (0140616_W)	243	29.8	42.1	50.8	59.6	71.7	81.4	91.4
Rheboksfontein (0141066_W)	235	38.8	54.8	66.1	77.6	93.3	105.7	118.8
Rietfontein 1								
Nelspoort (0093070_W)	226	35.1	49.3	59.4	69.6	83.5	94.6	106.2
Kampferskraal (0093074_W)	219	34.5	48.5	58.5	68.5	82.2	93.1	104.4
Ka 2								
Bakensrug (0093314_W)	218	34.5	48.6	58.5	68.5	82.3	93.2	104.5
Murraysburg (0117447_W)	257	33.3	47.0	56.5	66.2	79.4	90.0	101.0
Ossekuil 1								
Doornbosch (0095123_W)	407	45.2	63.7	76.7	89.8	107.8	122.0	137.0
Quaggasdrift (0095006_W)	411	48.4	68.1	82.1	96.0	115.3	130.5	146.4

2.3.4. Severe and Rare Phenomena

Historical weather observations in the region recorded by the SAWS (SAWS 2008) (Table 2-6) indicate frequent flood/heavy rain and tornado/strong winds events. Three tornadoes were recorded.

Table 2-6: Notable weather and weather related events in the study area

Year	Month	Day	Event	Place
1837	02	18	FLOODS	BEAUFORT WEST
1853	09	03	SNOW	GRAAFF-REINET
1856	06		FLOODS	BEAUFORT WEST
1869	10	23	FLOODS	BEAUFORT WEST
1870			FLOODS	BEAUFORT WEST
1871	02	27	FLOODS	VICTORIA WEST
1881	02		FLOODS	BEAUFORT WEST
1881	02		HAIL	BEAUFORT WEST
1886	07	11-14	SNOW	GRAAFF REINET
1905	03		FLOODS	BEAUFORT WEST
1907	01	08	TORNADO	JANSENVILLE
1918	03	14-15	FLOODS	BEAUFORT WEST
1920	02	1-4	FLOODS	BRITSTOWN
1920	02	1-4	FLOODS	DE AAR

Year	Month	Day	Event	Place
1920	02	1-4	FLOODS	PHILIPSTOWN
1921	12	28-29	FLOODS	ABERDEEN
1921	12	28-29	FLOODS	BEAUFORT WEST
1921	12	28-29	FLOODS	JANSENVILLE
1926	07	21-23	SNOW	GRAAFF-REINET
1933	08	28-29	SNOW	BEAUFORT WEST
1937	12	20	FLOODS	BEAUFORT WEST
1939	08	22-23	FLOODS	CARNARVON
1939	08	22-23	FLOODS	VICTORIA WEST
1940	02	16	FLOODS	BEAUFORT WEST
1940	02	16	FLOODS	NELSPOORT
1941	04	06	FLOODS	BEAUFORT WEST
1947	08	02	DUSTSTORM	BEAUFORT WEST
1947	08	02	DUSTSTORM	HUTCHINSON
1948	01	28	FLOODS	BEAUFORT WEST
1948	03	4	FLOODS	NELSPOORT
1950	05	12-18	FLOODS	BEAUFORT WEST
1950	05	12-18	FLOODS	VICTORIA WEST
1950	12	7	SNOW	ABERDEEN
1950	12	7	SNOW	MURRAYSBURG
1953	09	13-14	SNOW	DE AAR
1956	06	25-26	STRONG WIND	BEAUFORT WEST
1956	06	25-26	STRONG WIND	GRAAFF-REINET
1958	05	31	STRONG WIND	BEAUFORT WEST
1961	03	26-27	FLOODS	ABERDEEN
1961	03	26-27	FLOODS	JANSENVILLE
1961	03	26-27	FLOODS	LOXTON
1961	08	02	FLOODS	CARNARVON
1968	06	11-12	SNOW	JANSENVILLE
1973	08	19	SNOW	GRAAFF REINET
1974	03	07	FLOODS	GRAAFF REINET
1976	11	05	TORNADO	HANOVER
1977	05	07-08	SNOW	GRAAFF REINET
1981	08	28-29	SNOW	ABERDEEN
1981	08	28-29	SNOW	BEAUFORT WEST
1981	08	28-29	SNOW	DE AAR
1984	05	15-16	STRONG WIND	BEAUFORT WEST
1988	03	08-12	FLOODS	BRITSTOWN
1988	03	01	FLOODS	HUTCHINSON
1988	03	01	FLOODS	LOXTON
1988	03	08-12	FLOODS	LOXTON

Year	Month	Day	Event	Place
1988	03	01	FLOODS	NELSPOORT
1988	03	01	FLOODS	VICTORIA WEST
1988	03	08-12	FLOODS	VICTORIA WEST
1988	06	12	SNOW	GRAAFF REINET
1988	11	02	HAIL	PHILIPSTOWN
1989	04	22	HAIL	GRAAFF REINET
1989	07	30	STRONG WIND	GRAAFF REINET
1989	12	17	HAIL	MIDDELBURG – CAPE
1990	01	25	HAIL	JANSENVILLE
1990	01	25	STRONG WIND	JANSENVILLE
1990	10	15	SNOW	GRAAFF REINET
1990	10	18	SNOW	GRAAFF REINET
1990	10	18	SNOW	MIDDELBURG – CAPE
1991	06	06-08	SNOW	BEAUFORT WEST
1992	03	02	EXTREME COLD	MIDDELBURG – CAPE
1992	08	08-09	SNOW	ABERDEEN
1993	02	25	FLOODS	BEAUFORT WEST
1993	06	11	SNOW	DE AAR
1994	02	05-06	FLOODS	PETRUSVILLE
1994	03	04	HAIL	CARNARVON
1994	03	01	HAIL	DE AAR
1994	07	01	SNOW	BEAUFORT WEST
1995	05	21	SNOW	GRAAFF REINET
1995	07	18	SNOW	GRAAFF REINET
1996	12	27-30	FLOODS	GRAAFF REINET
2000	03	01-02	FLOODS	BEAUFORT WEST
2001	07	21	SNOW	GRAAFF REINET
2005	02	0	TORNADO	JANSENVILLE
2006	05	19	SNOW	WAPADSBERG PASS
2006	08	16	SNOW	GRAAFF REINET
2006	05	19	SNOW	LOOTSBERG PASS
2007	12	25-26	HIGH TEMPERTURES	BEAUFORT WEST
2007	12	30	HEAVY RAIN	BRITSTOWN
2007	12	30	STRONG WIND	BRITSTOWN
2007	12	30	HEAVY RAIN	DE AAR
2007	12	30	HAIL	DE AAR
2007	12	30	STRONG WIND	DE AAR
2007	12	30	HEAVY RAIN	HANOVER
2007	12	30	STRONG WIND	HANOVER
2007	12	30	HEAVY RAIN	PETRUSVILLE
2007	12	30	STRONG WIND	PETRUSVILLE

(i) Tropical Cyclones

The study area is not located on a hurricane track (i.e. between latitudes 5°S to 30°S) or adjacent to a warm ocean. Therefore it is not expected that the site will experience a hurricane, or at least there is a very low probability. However, it is important to note the difference between a hurricane and hurricane force winds. The latter refers to a wind speed scale called the Beaufort Scale, where hurricane force winds are those with speeds above 118 km/h. Exceedence of this wind speed (excluding the occurrence of tornadoes) has an estimated likelihood of about 0.1 per annum.

(ii) Tornadoes

Tornadoes in South Africa are typically associated with very hot air masses and severe thunderstorms. The most commonly method used to classify tornadoes is the 'Fujita-Pearson scale classification. This system classifies tornadoes in six intensities, ranging from F0 (no damage) to F5 (incredible damage). The intensity is based on the apparent damage to structures, the extent of the path and other descriptors from which wind speeds are then inferred.

About 65 percent of the South African tornadoes (Goliger 1997) are classified as F0 or F1 (light damage), while more than 90 percent are classified as F0, F1 or F2 (considerable damage, with maximum wind speeds of up to 70 m/s). Only about 8 percent of the documented tornadoes were F3, i.e. severe damage, with maximum wind speeds of up to 90 m/s. The tornado which occurred in Mount Ayliff in January 1999 was seemingly the most severe ever reported, with a classification of F4.

Based on an analysis of the occurrence of South African tornadoes for the period 1905 to 1997 by SAWS (Goliger *et al*, 1997), most tornadoes have been observed in Gauteng, the Free State, KwaZulu-Natal (along a line from Pietermaritzburg to Ladysmith) and the north-eastern areas of the Eastern Cape. Most of these events occur in mid-summer from November to January, although a large number of tornadoes have occurred in spring and early summer (September and October) and in the late summer and autumn (February to May). An analysis of tornado time of occurrence revealed that most events occurred in the late afternoon or early evening, typically between 16h00 and 19h00.

No evidence of tornadoes could be found for the study area. On the basis of the available tornado occurrences over a period from 1905 to 1997, Goliger *et al* (1997) estimated tornado (F1 and higher) probabilities for South Africa, as shown in Figure 2-5. According to study, the estimated tornado strike risk is about 1×10^{-5} per year per km^2 to the east, and becomes less moving towards the west of the study area.

Goliger *et al* (1997) report the highest wind speed in South Africa of 100 m/s being made during a tornado event. Furthermore, they estimate the likelihood of a tornado with a rotational wind speed of more than 90 m/s (324 km/h) would be less than 1.6 percent of all tornadoes. Given that the estimated probability of a tornado is 1×10^{-5} per year in the study area, this corresponds to a risk of about 1×10^{-7} per year.

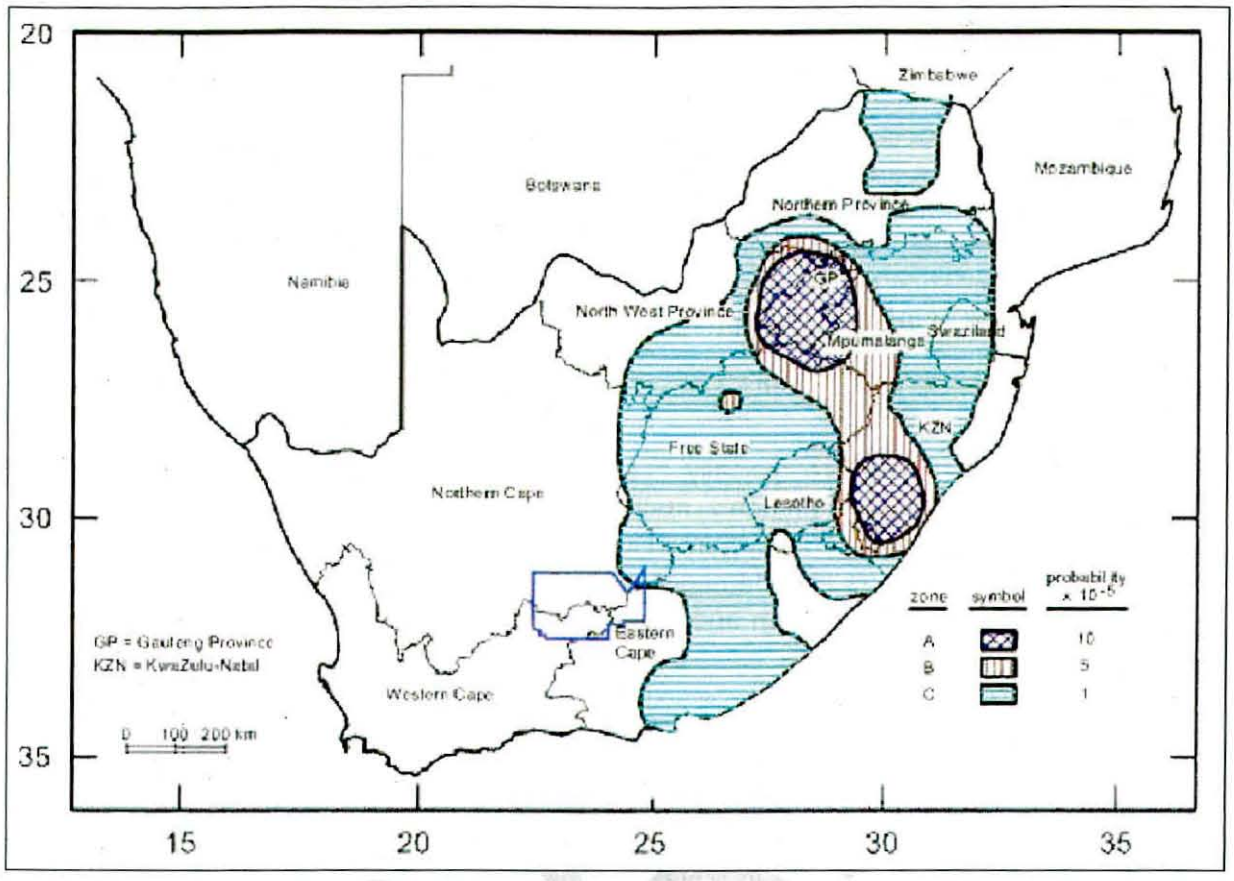

Figure 2-5: Mean annual rate of occurrence of tornadoes (excluding events with an intensity of F0 on Fujita Scale)

(iii) Hail

Formation of hail occurs as a result of very strong updrafts in convective thunderstorms of considerable vertical development. These updrafts carry hail into the uppermost ice regions of the cloud, which then fall into the supercooled layer below, which is still liquid at a temperature of less than 0°C. Very often hailstones are then lifted again by very strong updrafts back into the freezing upper part of the cloud again, where more clear ice and rime coalesce into consecutive layers on the hailstone. This vertical re-circulation may continue for some time but once the mass and weight of the hail is too great to be supported by air currents within the storm cell it falls to the ground (Geer 1996). The average number of days with hail in the study area is 1.7 per year.

(iv) Lightning

Lightning is the defining hazard of all thunderstorms and is caused by the differential between the positively charged upper section of a cloud and the negatively charged lower section. A new Lightning Detection Network (LDN) has recently (2006) been set up by the SAWS in South Africa. According to this network, the study area experiences between 1 (western portion) and 5 (north-eastern portion) lightning flashes per year per km².

2.4. Topography

Microclimates are dictated by the local topography. As shown in Figure 2-6, the most significant rise in topography is towards the southern sector. It is expected that these mountain ranges would determine the prevailing wind conditions to a great degree.

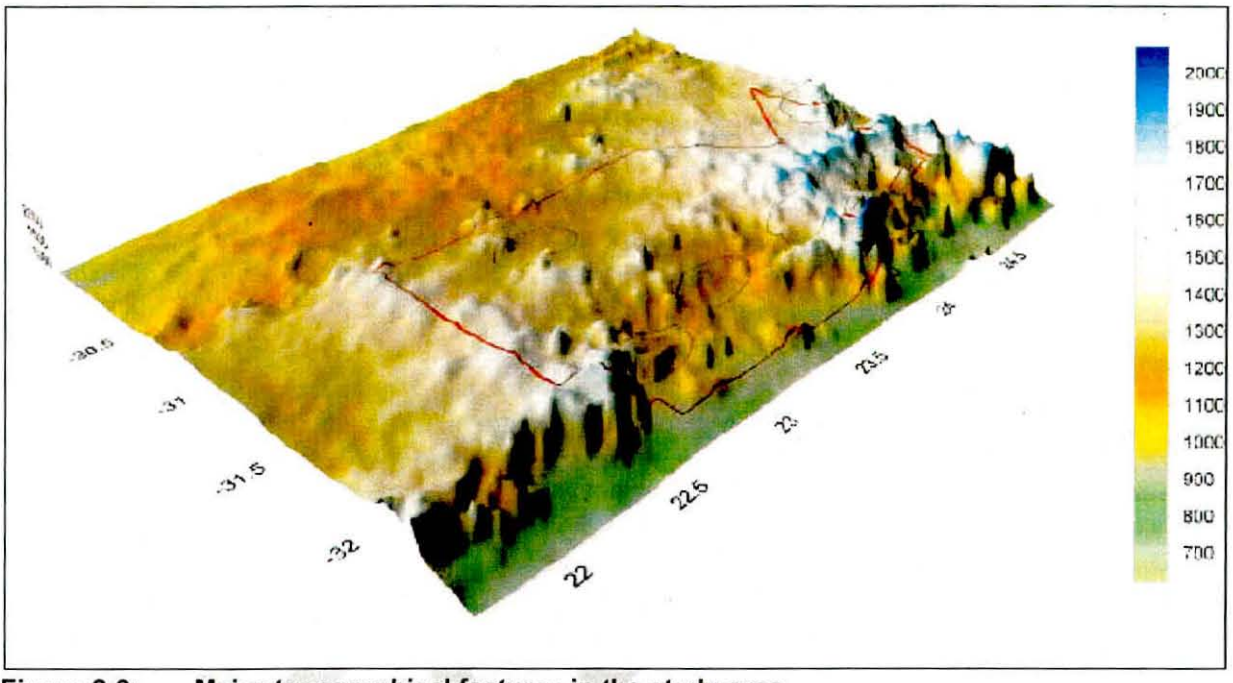

Figure 2-6: Major topographical features in the study area

2.5. Air Quality Regulations

2.5.1. Atmospheric Emissions Licence

The National Environmental Management: Air Quality Act (NEM AQA) (Act no.39 of 2004) commenced on the 11 September 2005 as published in the Government Gazette on the 9th of September 2005. Sections 21, 22, 36 to 49, 51(1)(e),51(1)(f), 51(3),60 and 61 were originally omitted, but came into effect on the 1 April 2010 (Government Gazette, 26 March 2010). The AQA was developed to reform and update air quality legislation in South Africa with the intention to reflect the overarching principles within the National Environmental Management Act. It also aims to comply with general environmental policies and to bring legislation in line with local and international good air quality management practices.

Given the specific requirements of the NEM AQA, various projects had to be initiated to ensure these requirements are met. One of these included the development of the *Listed Activities and Minimum National Emission Standards*. These standards were published on 31 March 2010 (Government Gazette No. 33064). The project aimed to establish minimum emission limits for a number of activities identified through a consultative process at several

forums. According to these standards, flares are not included under the NEM AQA. If the gas is to be used in reciprocating engines to produce electricity, the Act only comes into force if the power generation is above 50 MW (Category 1).

The operation of flares is mentioned under Category 2, and more specifically under Subcategory 2.1 Combustion installations. This category applies to the petroleum industry ("*the production of gaseous and liquid fuels as well as petrochemicals from crude oil, coal, gas or biomass*"). The discussion of the flare appears only in a footnote concerning the amount of sulphur dioxide emissions from the refinery. The note is essentially only a reminder that sulphur dioxide emissions can also come from flares and that this needs to be taken into account when the total sulphur dioxide "bubble" is calculated.

In the Act, a flare means a combustion device that uses an open flame to burn combustible gases with combustion air provided by ambient air around the flame. It further states that the combustion may be steam or air assisted. Flares may be either continuous or intermittent. This term includes both ground and elevated flares.

It may be argued that a flare is the "disposal of waste" and therefore may fall under Category 8: Disposal of hazardous and general waste. This category applies to facilities where general and hazardous waste including used oil or sludge from the treatment of used oil are incinerated (>10 kg/hour). The flare feed may perhaps be seen as the combustion of "waste" (i.e. incinerated). However, in the Act a flare is not considered as an incinerator although both involve combustions. Furthermore, the feed here is not waste, but rather the flare should be seen as a safety device. It is therefore the opinion that flares were not intended for inclusion in this category.

The last point to consider is the relatively short duration of the exploration (i.e. approximately 6 months). Under Category 2 (Petroleum Industry), it is stated that the standard excludes "test or experimental conditions", such as the exploration activities.

It is therefore concluded that the flare may not require an atmospheric emissions licence.

2.5.1. National Ambient Air Quality Standards

The National Ambient Air Quality Standards (NAAQS) was published in the Government Gazette on the 24th of December 2009. These standards were essentially based on the limit values developed originally by a technical committee and three working groups under the auspices of the South African Bureau of Standards (SABS). SABS was engaged to assist the Department of Environmental Affairs (DEA) in the facilitation of ambient air quality standards for criteria pollutants. Standards were determined based on international best practice for PM10, dustfall, SO_2, NO_2, ozone (O_3), CO, lead (Pb) and benzene (C_6H_6). These standards were first published for comment in the Government Gazette on 9 June 2007 with the revised standards published for comment on 13 March 2009. The final standards as published on 24 December 2009 are listed in Table 2-7.