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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Kuiseb Basin Water Resources Management Project

- Development of a Water Resources Plan for the Kuiseb Basin and Development of a Planning Procedure for use by Other Basins -

Part

GEOHYDROLOGY

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1.1 Inventory of relevant geological and geo-hydrological records and reports

1. **AIN (1999**/ Assessment Interconsult Namibia (PTY) LTD): Preliminary Environmental Assessment of proposed development at the Gobabeb Training and Research Centre.
2. **BATE, G.C. & WALKER, B.H. (1993)**: Water relations of the vegetation along the Kuiseb River, Namibia, Madoqua, 18 (2), 85-91.
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4. **BGR (1994)**: Groundwater Exploration/ **Vol. B-II**: Omaruru Alluvial Plains (OMAP) – Omaruru Delta (OMDEL) – Interpretation of Aero-Geophysical Data – Exploration Drilling Proposal: Open File Report (by A.BITTNER, K.-P. SENGPIEL, B. SIEMON, B. ROETTGER, W. VOSS & J. PIELAWA)
5. **BGR (1994):** Application of the Transient Electromagnetic Method for Groundwater Exploration in Namibia – Technical report **Vol. C-II**/ Part 1: Kuiseb Dune Area (by G. SCHAUMANN)
6. **BGR (1995)**: The BGR Geophysical Helicopter Survey in the Kuiseb Dune Area (Central Namib Desert),1992 - Technical Report **Vol. A-I** - (by K.-P. SENGPIEL, B. ROETTGER, H-J. REHLI, B. SIEMON, W. VOSS & J. PIELAWA)
7. **BGR (1995)**: The BGR Geophysical Helicopter Survey in the Omaruru Delta (OMDEL), 1992 - Technical Report **Vol. A-II** - (by K.-P. SENGPIEL, B. ROETTGER, H-J. REHLI, B. SIEMON, W. VOSS & J. PIELAWA)
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9. **BGR (1995)**: Groundwater Exploration in the Kuiseb Dune Area; Open File Report **Vol. D-I** / Part 1 (Text)/ Part 2 (Annexures A)/ Part 3 (Annexures B + C) (by R. LENZ, H. GROBBELAAR & M. DJAMA)
10. **BGR (1995)**: Kuiseb Dune Area; Open File Report **Vol. E-I** / Part 1 (Text)/ Part 2 (Figures: Aquifer tests WW 33184 and TP 09 to TP 17)/ Part 3 (Figures: Drawdown Calculations: Palaeochannels 01, 02 and 03) (by G. SCHMIDT)
11. **BGR (1996)**: The BGR Geophysical Helicopter Survey in the Omaruru Alluvial Plains (OMAP), 1993 - Technical Report **Vol. A-IV** - (by K.-P. SENGPIEL, J. PIELAWA, H-J. REHLI, B. ROETTGER & W. VOSS)
12. **BGR (1998)**: German-Namibian Groundwater Exploration Project – Technical Cooperation Project No.: 89.2034.0 – Reports on Hydrogeological and Isotope Investigations **Vol. D-II** – Isotope Hydrological Study on the Kuiseb Dune Area, Koichab Area (Lüderitz) and Omaruru Delta (OMDEL) (Central and Southern Namib Desert) (by D. PLOETHNER)
13. **BGR (1998)**: German-Namibian Groundwater Exploration Project – Technical Cooperation Project No.: 89.2034.0 – Follow Up Report **Vol.7** – Kuiseb Dune Area/ Assessment of the Groundwater Potential (by G. SCHMIDT)
14. **BGR (2000)**: Calculated Configuration of the Magnetic Basement in the Kuiseb Helicopter Survey Area; Follow Up Report **Vol. 3** (by S. MAUS)
15. **BGR (2000)**: Summary Report/ Background Scope and Results of the Project – Summary, Conclusions and Recommendations: Kuiseb Dune Area, Omaruru Delta (OMDEL), Omaruru Alluvial Plains (OMAP), Otavi Mountain Land and Eastern Owambo Area (by D. PLOETHNER)
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21. **DRFN (1994)**: Water Usage Patterns In The Kuiseb Catchment Area – with emphasis on sustainable use.- (by DAUSAB, F., FRANCIS, G., JOEHR, G., KAMBATUKU, J., MOLAPO, M., SHANYENGANA, E., SWARTZ, S.); facilitated by Desert Research Foundation of Namibia (DRFN), sponsored by Swedish International Development Authority (SIDA).
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27. **MUINJO, K. (1998)**: Groundwater modelling of the Lower Kuiseb River between Rooibank and Gobabeb gauging stations. Master of Science degree project, Department of Civil and Environmental Engineering, land and Water Resources. Thesis report series 1998:8, Royal Institute of Technology, Stockholm, DWA Windhoek.
28. **NAMWATER (1998)**: The Impact of the 1997 Flood Events in the Lower Kuiseb River on the Recharge to the Lower Kuiseb Aquifers.- Report REF: NWC-WR-7/1/6/3-REP, Geohydrology Division/ NamWater, Windhoek.
29. **NAMWATER (2000)**: Situation Assessment on Kuiseb Well Field. Report REF: NWC-IP-KUISE00-01, Report by Infrastructure Planning/ NamWater, Windhoek.
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31. **SHANYENGANA, E.S. (1997)**: Gobabeb Training and Research Centre Programme: Appropriate technology for arid lands. Desert Research Foundation of Namibia. Windhoek, 1-56.
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1.2 Overviews of Main Hydrological & Geological Features

1.2.1 Hydrology

The Kuiseb, an ephemeral river with a length of 560 km, drains a catchment of approx. 14 700 km^2 in west-central Namibia. Only the upper 9 000 km^2 of this area are considered to be producing significant runoff, while the remaining part of the catchment area forms an arid to hyper-arid desert plain yielding runoff only in exceptionally wet years (HATTLE 1985).
The Kuiseb river is bound to a clearly defined river bed until it reaches the lowlands in the delta area (Annex 1). The *Upper Kuiseb River* reaches from the Khomas Highland through the escarpment in a generally well incised river bed in SW direction over 220 km until Hudaob. The *Middle Kuiseb River*, between Hudaob and Natab, flows for 40 km in WNW direction within a narrow, canyon-like river bed. From Natab downstream, the *Lower Kuiseb River* changes to a general NW direction and flows over 75 km within a broad, sandy river bed towards the delta region W of Rooibank.

Hydraulically the Kuiseb is the most thoroughly monitored river of western Namibia, with 8 rainfall and 14 flow gauging stations distributed within the catchment.
Records at *Gobabeb* indicate the river flows between 0-105 days per year. In the early 80’s the river did not flow for more than 4 years (SHANYENGANA 1997). The WNNR REPORT (1984) states that between 1837 and 1984 the Kuiseb flow only reached the Atlantic 15 times.
While BLOM (1978) estimated a long term average **annual runoff** of 35.5 x 10^{-6} m^3, JACOBSON (1997) calculated a mean annual runoff from 1979 – 1993 of 4.65 x 10^{-6} m^3. The annual range however is between 0 – 220 x 10^{-6} m^3 according to AIN (1999) & HUNTLEY (1985). The latter one gives a mean of 40 x 10^{-6} m^3 at the base of the escarpment.
BLOM (1978) estimates an average flood loss downstream of the Gaub confluence up to Rooibank due to evaporation and infiltration into the alluvial bed at 20.9 x 10^{-6} m^3.

The **rainfall** in the catchment declines from a mean annual rainfall of approx. 360 mm in the headwaters to almost zero at the coast (JACOBSON 1997/ BGR 1998).
According to HUNTLEY (1985) the Kuiseb catchment receives on average only 159 mm rainfall per annum.
DRFN (1994) states that 660 M. m^3 of water fall as rain in the upper catchment and 21 M. m^3 pass the Kuiseb-Gaub confluence, 2 M. m^3 run off are measured at Swartbank and 0.6 M. m^3 at Rooibank. According to that report the highly variable upper catchment runoff shows a high of 105.9 M. m^3 /a and a low of 0.0065 M. m^3 /a recorded at Schlesien Weir.

1.2.2 Geology

The Namib desert is underlain by *Precambrian bedrock* consisting of *granites, gneisses and schists.* These are separated from younger *Tertiary & Quarternary deposits* by the *Namib unconformity surface* formed during the Late Cretaceous erosional phase. Outcrops of Precambrian rocks can be found all over the Central Namib Region. The oldest Tertiary deposits (50 – 20 Ma) pertain to the cross-bedded, aeolian *Tsondab Sandstone Formation*, which underlies most of the Central Namib Desert south of the Kuiseb River and was deposited under arid conditions. The *Tsondab Sandstone Formation*, a precursor of the present Namib Sand Sea, is generally 45 to 90 m thick, but reaches a thickness of over 200 m in the eastern part of the Namib Sand Sea (BESLER & MARKER 1979).
In the area of the Kuiseb Valley the *Tsondab Sandstone Formation* is overlain unconformably by the well rounded quartzite and vein quartz gravels of the *tertiary Karpfenkliff Conglomerate Formation* (WARD 1984).This Conglomerate and its equivalents in the Tsondab and Tsauchab valleys represent the earliest evidence of a well integrated drainage in the central Namib. These tertiary fluvial deposits are extensively calcified, as the Tsondab Sandstone shows with an up to 5 m thick pedogenic calcrete horizon on adjacent interfluves, representing a long period of landform stability in a semiarid climate.
The geological sequence of the Namib Desert north of the Kuiseb river is overlain by alluvial sediments of the *Namib Group (Early Miocene)* indicating a wetter, more humid climate with sporadic high energy flow events. Extensive *Calcrete formation* occurred at the end of the Miocene. The *Late Tertiary deposits* of the *Sossus Sand Formation* indicate a return to arid conditions. The *Pleistocene sediments* show a mostly arid climate, which alternates sporadically with short slightly wetter periods.
Evidence of lacustrine and moister conditions can be seen in the *Oswater Conglomerate*, *Hudaob Tufa deposits, the Khommabes Carbonates, the Homeb Silts, the Awa Gamteb muds* and the pebble to cobble sized *Gobabeb Gravel formation* (which all make up *Kuiseb Palaeochannel Fills*).
Ephemeral rivers within the Kuiseb Delta have deposited the most recent sediments in the form of sand deposits and silty river alluvium during floods. The modern coastline with its headlands, lagoons, bays and sabkhas is a result of the interaction of eolian, coastal and fluvial processes.

The Kuiseb rises on the interior plateau of central Namibia, the *Khomas Hochland*, at an elevation of approx. 2000 m. Westwards from the headwaters the river has eroded a shallow, sinuous valley into *Late Precambrian metasediments,* largely composed of *schists* and *quarzites* which provide a large proportion of sandy bed loads transported within the river's lower reaches (WARD 1987).
West of the escarpment separating the inland plateau from the coastal plains, the river has incised a deep canyon (>200 m) in similar rocks. The river is highly confined herein, often flowing over *bedrock with no alluvial cover* due to the comparatively steep gradient (0.003 – 0.004 m/m) and narrow channel (<100 m). The channel broadens 65 km from the coast (approx. 45 km above *Gobabeb*), freeing the river channel to expand onto an increasingly wide (ephemeral or dry) delta and floodplain, the *Kuiseb Delta*. Approx. 42 km below *Gobabeb station* the floodplain width increases to over 1 km.
Within 20 km from the coast low crescentic dunes cross the river, resulting in poorly defined channels terminating on coastal flats in the vicinity of Walvis Bay. Gradients below the canyon average 0.001-0.002 m/m, increasing again to 0.004 m/m within 60 km from the coast, resulting in a slightly convex longitudinal profile in the lower river. When in flood, the river's lower reaches transport a sandy bed load and a suspended load high in silts. The sandy channel sediments within the lower 150 km are largely devoid of cobble or bedrock, excluding occasional bedrock dikes which cross the channel and form local knick points in the longitudinal profile (WARD 1987).
The Kuiseb delineates the *gravel plains of the Namib*, underlain by massive granites and covered by thin soils in the north, from the *dune fields* of the *Namib Sand Sea* in the south.

1.2.3 Main Aquifer Types

According to KUELLS & HEIDBUECHEL (2006) the main aquifer types are the following:

- **Alluvium/** Hydraulic Conductivity 2.0 x 10^{-3} m/s / Porosity 30 % / Layer Thickness 30 m/ Storativity S=0.133 (at Rooibank) or S=0.06 to 0.08 (at Swartbank)
- **Palaeochannels**/ Hydraulic Conductivity 1.0 x 10^{-6} m/s [BGR 1998/Vol 7: 3.1 x 10^{-6} m/s] / Porosity 25 % / Layer Thickness 105 m/ Storativity S=0.046 or 4.6 %
- **Sandstone**/ Hydraulic Conductivity 3.0 x 10^{-6} m/s / Porosity 7 % / Layer Thickness 100 m
- Basement/ Hydraulic Conductivity 1.55 x 10^{-8} m/s / Porosity 0.1 % / Layer Thickness down to sea level

BGR (1998/Vol 7) give the following transmissivities, saturated thicknesses & hydraulic conductivities (including a mean overall porosity of n=0.15):

- **Kuiseb River Sediments**: 150 – 1600 m^2/d / Saturated thickness 15 m/ Hydraulic Conductivity 10^{-4} - 10^{-3} m/s
- **Palaeochannel Sediments** : 6 m^2/d
- **Tsondab Sandstone**: 4 m^2/d
- Basement: 0.03 m^2/d

Values from other studies for **Kuiseb River Sediments**:

- BLOM (1978):
- Hydraulic Conductivity 3 x 10^{-4} to 2 x 10^{-3} m/s (Mean value K= 9 x 10^{-4} m/s or K= 79 m/d)/ Storage Coefficients between 0.09 and 0.25 (Mean value 0.17)
- VAN RENSBURG (1992/ for the period 1988 - 1990):
- Hydraulic Conductivity K= 2 x 10^{-3} m/s or K= 134 m/d/ Storage Coefficient S= 0.13

According to AIN (1999) there are **2 alluvial aquifers** (on top of each other) with differing water qualities in the *Kuiseb at Gobabeb*:

- **A freshwater aquifer** underlain by **a denser & more saline aquifer.** In places the interface between the upper and lower groundwater is sharp but in other places a zone of mixing is present. The thickness of the fresh-water layer varies between 3 and 15 m, the water quality is also not constant.

The *Kuiseb Alluvial Aquifer* is not continuous. At several locations basement rocks crop out on either side of the river channel restricting the lateral extent of the alluvium. Upstream of *Gobabeb* and approx. 5 km downstream, near *Soetrivier*, such outcrops exist. In the vicinity of the latter, geophysical surveying suggested that the depth to fresh bedrock is very limited. Such lateral and vertical restrictions to the alluvial channel constitute possible barriers to GW-flow.
The average alluvial width is 150 m, the porosity 35 % and the saturated thickness 10 m according to AIN (1999) while BATE & WALKER (1991) give an average alluvial width of 307 m and a thickness of 10 m.

According to BGR (1995/Vol E-I) the above values reveal that the palaeochannels' fill is an unconfined, low permeable aquifer which will not maintain a viable well field. Comparatively the Kuiseb River deposits have more favourable aquifer parameters according to VAN RENSBURG (1992) & CAWMP (1993).
On the other hand, although the information on the Tsondab Sandstone aquifer parameters is still poor, it is assumed by BGR (1998/Vol D-II) that **the palaeochannel fill is the major aquifer of the Kuiseb Dune Area** due to its lower grade of consolidation. This was also confirmed in subsequent pumping tests by DWAF in the late 1990's, where the paleao-channels had good hydraulic properties closer to the sea – just north of Sandwich Harbour - whith good yields and very little drawdown.

According to BGR (1998/Vol D-II) the stored GW-reserves in the palaeochannels is assessed to a volume of 75 Mm^3 brackish and 280 Mm^3 fresh GW using a storativity of 4.6 %.
According to BGR (1995/Vol D-I) the amount of water available in the palaeochannel aquifer is estimated to be about 340 Mm^3 (in contrast to a former estimate of 1500 Mio. m^3 [VAN ZIJL & HUYSSEN 1967]), of which about 100 Mm^3 are brackish. A further 160 Mm^3 is in the *Tsondab Sandstone.* This estimate of a total of 500 Mm^3 is based on assumed and measured thicknesses of saturated sediments of 15 – 30 m and an effective pore volume of 0.04 – 0.05 (BGR 1995/Vol D-I).

1.3 Groundwater-Dependant Ecosystems (see also B 7 & B 8)

The Kuiseb plain is considered a linear oasis or a green belt in the desert. While in the desert itself there is nearly no vegetation, the river plain maintains a woodland vegetation, normally composed of Anaboom, Camel thorn, Wild tamarisk, Ebony tree, Mustard tree and Sycamore fig. Famous is the Nara melon, which is covering small sand dunes within the river bed and also its southern flank (BGR 1995/Vol D-I).

BLOM (1978) mentions that downstream of Rooibank the tree vegetation with a few exceptions disappears altogether from the river plain.
The vegetation cover depends for their survival on the infrequent floods and on the subsurface water flow. The *reduction of the vegetation cover* reported on the last decades, may be caused by different effects:
A very important one has been certainly the *lowering of the GW-table due to the intensive GW-abstractions in the lower Kuiseb valley* (BGR 1995/Vol D-I).
But also the domestic stocks of the native Topnaar communities may have contributed so far, because their goats feed especially on new sprouts and young trees, hampering these new tree generations to grow up.

According to HUNTLEY (1985) the consequences of the increased use of the water resources of the Kuiseb basin were believed to cause a lowering of the water table which would result in:

- the death of the dense acacia woodland which forms a linear oasis across the desert
- the unhindered northward advance of dunes from the Namib Sand Sea
- the termination of subsurface flow of freshwater from the Kuiseb to Sandwich Lagoon
- the depletion of drought reserves for plains game and Topnaar domestic stock through the loss of the acacia woodland and associated vegetation
- and ultimately the siltation of Walvis Bay Lagoon.

1.4 Gaps and shortcomings in information, knowledge and measures

Information gaps exist regarding the <u>entire</u> Kuiseb Basin. There are much more GW-research-data available in MAWF/ DWAF for the downstream area than for the upstream area.

2 Water resources

2.1 Inventory of relevant records and reports of presently used groundwater sources and unutilised groundwater resources

1. **BGR (1995)**: Groundwater Exploration in the Kuiseb Dune Area; Open File Report **Vol. D-I** / Part 1 (Text)/ Part 2 (Annexures A)/ Part 3 (Annexures B + C) (by R. LENZ, H. GROBBELAAR & M. DJAMA)

2. **BGR (1998)**: German-Namibian Groundwater Exploration Project – Technical Cooperation Project No.: 89.2034.0 – Follow Up Report **Vol.7** – Kuiseb Dune Area/ Assessment of the Groundwater Potential (by G. SCHMIDT)
3. **CHRISTELIS, G. & STRUCKMEIER, W. (Ed.) (2001)**: Groundwater in Namibia, an explanation to the Hydrogeological Map [HYMNAM/ Hydrogeological Map of Namibia 2001]. 1st edition, BGR & DWA & GSN, Windhoek 2001.
4. **CAWMP/ DWA (1993)**: Central Area Water Master Plan: Phase 1/ Republic of Namibia, Ministry of Agriculture, Water and Rural Development (DWA), German Technical Cooperation (GTZ), Consulting Engineers Salzgitter (CES), Lund Consulting Engineers (LCE), Windhoek Consulting Engineers (WCE). Windhoek, Namibia
5. **DRFN (1994)**: Water Usage Patterns In The Kuiseb Catchment Area – with emphasis on sustainable use.- (by DAUSAB, F., FRANCIS, G., JOEHR, G., KAMBATUKU, J., MOLAPO, M., SHANYENGANA, E., SWARTZ, S.); facilitated by Desert Research Foundation of Namibia (DRFN), sponsored by Swedish International Development Authority (SIDA).
6. **GKW, PARKMAN, BICON (1996):** Water Supply to the Central Namib Area of Namibia , Feasibility Study, Final report, Volume 1, Summary report, Kreditanstalt fuer Wiederaufbau KfW, Ministry of Agriculture, water and rural Development, DWA Windhoek, DWA-File No. 13/7/1/6/1
7. **JOBSON, H.E. & HARBAUGH, A.W. (1999):** Modifications to the diffusion analogy surface water flow model (DAFLOW) for coupling to the modular finite-difference groundwater flow model (MODFLOW). U.S. Geological Survey, open-file Report 99-217.
8. **KUELLS,C. & HEIDBUECHEL, I. (2006)**: Application of a Coupled Surface Water/ Groundwater Model for Estimating Groundwater Recharge from Flash Floods – Results of the application to the Kuiseb Delta – WADE PROJECT GOCE-CT-2003-506680-WADE (2002-2006).
9. **NAMWATER (1998)**: The Impact of the 1997 Flood Events in the Lower Kuiseb River on the Recharge to the Lower Kuiseb Aquifers.- Report REF: NWC-WR-7/1/6/3-REP, compiled by Geohydrology Division, Windhoek.
10. **NAMWATER (2000)**: Situation Assessment on Kuiseb Well Field. Report REF: NWC-IP-KUISE00-01, Report by Infrastructure Planning/ NamWater, Windhoek.
11. **NAMWATER (2001)**: Re-Assessment of the long-term sustainable yield of the Lower Kuiseb Aquifers/ Final report NWC-WR-CNP-REP, Water Resources Division/ Geohydrology/ NamWater, Windhoek.
12. **MUINJO, K. (1998)**: Groundwater modelling of the Lower Kuiseb River between Rooibank and Gobabeb gauging stations. Master of Science degree project, Department of Civil and Environmental Engineering, land and Water Resources. Thesis report series 1998:8, Royal Institute of Technology, Stockholm, DWA Windhoek.

2.2 Concise description of these features/resources, including undeveloped water resource potential

The Kuiseb River in central & western Namibia is one of the most heavily used rivers in the country, well known for providing all the water used in Walvis Bay and part of that used in Swakopmund and Rössing Mine and Arandis. In addition it supports the farming activities and production of the Topnaars (400 communal farmers in 10 villages) along the lower water course, the activities of researchers and educators working with the Namib Research Institute at Gobabeb (the *Gobabeb Desert Research Station of DRFN* is supplied with a borehole on the northern bank of the Kuiseb river) and animals living in the Namib-Naukluft Park. It also supports the production from 109 commercial farms in the upper reaches of its catchment area (DRFN 1994).

According to DRFN (1994) the consumption was the following in detail:

- 0.6 Mm^3/a on 109 farms (ground dams & boreholes, for livestock (90 %) and domestic purposes (10 %)
- 0.006 Mm^3 /a by 400 Topnaar communal farmers in 10 villages for livestock (58 %) and domestic purposes (42 %)

- 0.007 Mm^3 /a by the Namib Research Institute at Gobabeb (for domestic purposes, 86 % for gardening)
- 4.3 Mm^3 /a for water supply of Walvis Bay (from Rooibank Aquifer/ 72 % for domestic purposes, industrial use 28 %; 36 % of the town's entire water consumption were used for gardening)
- 2.9 Mm^3 /a for water supply of Swakopmund (from Swartbank Aquifer/ 96 % for domestic purposes, light industrial use 4 %)
- 3.0 Mm^3 /a for Rössing Uranium Mine and the town of Arandis (from a reservoir in Swakopmund, supplied by Kuiseb & Omaruru aquifers)
- Evaporation & gardening were identified as major sources for water use & losses

The amount of water available in the palaeochannel aquifer (the only existing prospective aquifer) is estimated to be about 340 Mm^3 (in contrast to a former estimate of 1500 Mm^3 [VAN ZIJL & HUYSSEN 1967]), of which about 100 Mm^3 are brackish. A further 160 Mm^3 is in the *Tsondab Sandstone.* This estimate of a total of 500 Mm^3 is based on assumed and measured thicknesses of saturated sediments of 15 – 30 m and an effective pore volume of 0.04 – 0.05 (BGR 1995/Vol D-I).

BGR 1998/Vol D-II describe the palaeochannels as following:
The palaeochannels (Annex 5) are 20 to 65 km in length and <0.5 to 5 km in width which are covered by 15 to 70 m (average 35 m) dune sand below the inter-dune valleys. They predominantly contain a 40 to 90 m (average 55 m) thick calcareous silty fine sand, locally medium to coarse-grained sand. In the southernmost palaeochannel the sediments attain a max. thickness of 120 m of which 60 % is marl. The palaeochannel has a saturated thickness of between 20 – 40 m which is maintained by indirect recharge from the Kuiseb river, which totals 0.42 Mm^3/a.

Calculations to predict the amount of lowering of the GW-table show that pumping will mainly take GW from the sediments of the palaeochannels. With an annual extraction of 5 Mm^3 for 20 years only about 3 % of the water will be taken from the *Tsondab Sandstone*.
The water supply at the central West Coast is based on GW-abstraction from the lower reaches of two ephemeral river systems, the Kuiseb River some 20 km south of Walvis bay and further southeast, and the Omaruru River some 80 km north of Swakopmund.
There are major schemes for water supply located in the lower part of the Kuiseb. The water supply of *Walvis Bay* and of the *Uranium Mine Rössing* are supplied from a GW-abstraction scheme located in the lower Kuiseb river delta, operated by Nam Water (see down). Other areas to be supplied are major tourist centres like *Swakopmund* and *Henties Bay*.
Since 1923 Groundwater has been continuously abstracted from the lower Kuiseb River, near the village of Rooibank.From 1960 onwards the Groundwater-abstraction in the Kuiseb area increased considerably due to new production fields going into operation in:

- B-area in 1966
- Swartbank in 1976
- Dorop South in 1992.

NamWater is operating the abstraction areas Rooibank A & B, Dorop North & South and Swartbank for the water supply of Walvis Bay (Annex 3, 4 & 6). According to BGR (1995/Vol D-I/ table p.4) and NamWater (2000/Annex) 58 production wells are located in the lower Kuiseb abstraction areas.
The pump rate development over the years can be studied in detail in NamWater (2000 & 2001). Over the period between 1986 and 2000, abstraction from the Lower Kuiseb Aquifers averaged 7.7 Mm^3/a. Just after the development of the Swartbank Aquifer abstraction peaked between 13 and 16 Mm^3/annum.

In 1977/78 annual Groundwater-production reached its total peak with 16.53 Mm^3/a (BGR 1995/Vol D-I). After completion of the Omaruru Delta GW-Abstraction Scheme in 1978 the production of the

Kuiseb aquifers has been cut back. According to BGR (1995/Vol D-I) and NamWater (2001) the annual abstraction was surpassing the mean annual recharge **and the reserves continue being depleted until present.** As an effect pumping rates of the production wells had to be reduced and some wells fell even dry. The abstraction had reached about 8 Mm^3 and is now being reduced to 3-4 Mm^3 due to studies on Groundwater-recharge (NamWater 2001; KUELLS & HEIDBUECHEL 2006). According to the CAWMP (Phase 1/ DWA 1993) the water demand for 2005 was 18 Mm^3/a and will be 29 Mm^3 for 2020.
The growing demand for the time ahead requires additional water supply by groundwater, and in the longer run, by surface-water dams or desalination plants (BGR 1995/Vol D-I). The latter one is now (2008) under construction at Wlotzkasbaken (north of Swakopmund) with financial support from the mining industry and will go into operation by end of 2009.

The Central Namib Area consists of the Kuiseb and Omdel water abstraction schemes, which 2 aquifer systems at the coast at the end of 2007 had a calculated total abstractable reserve of 204 Mm^3 (which has to be confirmed by more research in the future). The running average abstraction at the coast at the end of 2007 was ~ 1.15 Mm^3/month, which included the potable water supply to Rössing and Langer Heinrich. The current available natural water resources of the Kuiseb & Omdel scheme, excluding the recent upgrades at Omdel to accommodate Langer Heinrich, are 12.9 Mm^3/a. This can be increased to a max. of 15.9 Mm^3/a by developing other natural resources within both catchments. Such 15.9 Mm^3/a sustainable yield of all the available natural resources will not be sufficient to supply in the demand of the proposed new uranium mines in the Erongo region and the *construction of a desalination plant* (see above) is seen as the most viable solution to meet the water demand of these new uranium mines. NamWater and any bulk user/ private utility taking water from natural resources must have valid *abstraction licenses* from DWAF, while **NamWater must prepare & present a *Water Master Plan* for the Central Namib to DWAF** (see also Chapter D. First cycle and future action plans) to ensure the sustainable use of the resources. As well all bulk water users should develop a Water Conservation & Demand Management Plan, ensuring the optimum use of water (WATER & WASTE MANAGEMENT TECHNICAL ADVISORY COMMITTEE/WWM TAC of THE CHAMBER OF MINES OF NAMIBIA / unpublished meeting minutes 02/ 2008).

The aquifer below the lower Kuiseb provides a considerable proportion of the water supply. Annual production between 1986 and 1997 in the area studied between *Swartbank* and *Rooibank* averaged 4 Mm^3/a. A further 1 Mm^3/a have been taken from additional wells since 1995. The wells are not usually pumped throughout the day. How long a well is pumped depends on how full the storage tanks/reservoirs are. Alternating well groups are pumped (BGR 1998/Vol 7).
During the BGR-investigations the Groundwater-table was regularly monitored by hand measurements, at 4 wells the levels were recorded automatically. The density of the observation wells was suitable for describing the Groundwater-Level over relatively large areas. **Since 1982 the Groundwater-table has dropped 2 – 6 m** (BGR 1998/Vol 7). During the 1997 floods the Groundwater-table rose up to 6 m in wells near the river.

Prior to MUINJO's findings in 1998 the sustainable yield for all the aquifers was assessed to be in total 3.2 Mm^3/a, with a further 1.2 Mm^3/a, which represents a mining yield of the Dorob South abstraction area. The Swartbank waterworks comprising 22 production wells abstracted a max. of 5.4 Mm^3/a for 1988 after which production rates were reduced, averaging 3.75 Mm^3/a for the years 1989 to 1991. The Rooibank A-scheme, comprising 14 production wells, increased its abstraction from 2.3 Mm^3/a in 1985 to 4.2 Mm^3/a in 1991.

Due to this **over-exploitation** the average saturated thickness diminished by 6 to 10 m between Klipneus, Swartbank and Rooibank A from 1972/75 to 1993/94 resulting in a reduction of the abstractable GW reserves from 40 to 19 Mm^3 (at Rooibank A) and 38 to 21 Mm^3 (at Swartbank).

According to NamWater (1998) the Lower Kuiseb Aquifers, comprising the Delta Aquifer (Dorop South & Rooibank B well fields) and the Swartbank/ Rooibank A Aquifer were being overutilized to supply the demand of consumers in the Central Namib Area. This situation would probably prevail until the planned desalination plant is in operation. The average abstraction from both areas were 3.62 Mm^3/a and 4.72 Mm^3/a respectively.

Further possible areas of GW-development in the Kuiseb area not influencing the current utilised resources were also included into the sustainable yield calculations by NamWater (2001): **The most promising area regarding both accessibility and yield potential is the J-line area (south of the Swartbank Area/ Annex 5)**, **which could yield up to an estimated 1.5 Mm^3/a** without any negative impact on the current areas utilised and the environment.

By the development of other areas in the Kuiseb Aquifer the sustainability of the Kuiseb Aquifers might be increased to an average of **11 Mm^3/a** if it is feasible or practical to develop and utilise the other resources mentioned in NamWater (2001/Table C).

2.3 Recharge dynamics and rates, discharge, abstractions and the possible over-exploitation of groundwater

Recharge to the alluvial aquifers occurs mainly via vertical infiltration of runoff down the present day Kuiseb river and from through-flow within the alluvial aquifers, mainly during ephemeral flash floods. During those the *duration* of the floods is the most important factor concerning recharge and not their *intensity.*
Owing to the high evaporation rates, rain in the desert areas does not contribute significantly to groundwater recharge.
Depending on the intensity and location of rainfall in the catchment area, flash floods occur in the main streams. The amount of water and the duration varies. Every several decades a flash flood in the Kuiseb reaches the Atlantic, the last time in the 1962/63 rain season. Flash floods since then have gone no further than *Rooibank* (to *Dorop* in 1996/97).
Most of the flash floods occur in the eastern half of the catchment area and can recharge the groundwater below the dry bed of the lower Kuiseb.
At some places along the river bed relatively small amounts of water from the flash floods reach the aquifer in the dunes area via the palaeochannels of the Kuiseb. Such conditions exist between *Gobabeb* and *Rooibank.* This area was mapped as part of hydrogeological studies based on data from an aerial geophysical survey (BGR 1995/Vol B-III, SENGPIEL & SIEMON 1997). Correlation of borehole data with the maps of apparent resistivity prepared from the electromagnetic data show that the palaeochannels of the Kuiseb cut through the *Tsondab Sandstone* into the basement.
The amount of water available in the palaeochannel aquifer (the only existing prospective aquifer) is estimated to be about 340 Mm^3 (in contrast to a former estimate of 1500 Mm^3 [VAN ZIJL & HUYSSEN 1967]), of which about 100 Mm^3 are brackish. A further 160 Mm^3 is available in the *Tsondab Sandstone.* This estimate of a total of 500 Mm^3 is based on assumed and measured thicknesses of saturated sediments of 15 – 30 m and an effective pore volume of 0.04 – 0.05 (BGR 1995/Vol D-I).
Calculations to predict the amount of lowering of the Groundwater-table show that pumping will mainly take Groundwater from the sediments of the palaeochannels. With an annual extraction of 5 Mm^3 for 20 years only about 3 % of the water will be taken from the *Tsondab Sandstone*.
However, salinity changes indicate an inflow from saline source to the alluvium as well from the granites or from the basin as subsurface discharge.

The DWAF has installed gauging stations at various points along the Kuiseb. Records, including length of the flood, are available for the period since 1961 at the *Gobabeb* and *Rooibank* stations. Between 1961 and 1982 the floods lasted an average of a month. Discharge averaged 17.6 Mm^3 at

Gobabeb and 9.5 Mm^3 at *Rooibank.* Since 1982 the floods at *Gobabeb* have lasted only half as long (about 14 days) with an average of 9.1 Mm^3. Since 1982 significant amounts were measured at *Rooibank* only in 1993 and 1997.
The measurements at the *Swartbank* gauging station are incomplete for the period since 1989, because the river bed has moved in some places (BGR 1998/Vol 7).
The recharge estimates assume that only heavy flooding contributes to local GW-recharge. Hence the water must reach at least *Rooibank*.

BGR (1998/Vol 7) carried out model calculations [MUINJO 1998] to simulate the effects of flash floods on the Groundwater-system in order to determine the magnitude of potential Groundwater-recharge. According to these investigations inflow at *Swartbank* is held at a constant annual 4 Mm^3, estimated from the gradient and transmissivity. Small amounts of water flow into palaeochannels (0.12 and 0.07Mm^3) in the dunes area.
The effects of flash floods in 1985, 1988 and 1997 were simulated using the actual Groundwater-production since 1986 and assumed values for the rates of infiltration. These calculations indicate infiltration of 0.1 Mm^3 per year from the relatively small amounts of water in the floods of 1985 and 1988. Simulation of the large floods of 1997 (43 days) indicate infiltration of only 0.84 Mm^3, which is in agreement with the calculated Groundwater-recharge of about 1 Mm^3 (BGR 1998/Vol 7).

The grain size distribution near *Gobabeb* site (Kuiseb active channel & floodplain) is heterogeneous. The surface channel is often covered by a *silt layer*, which varies from 1 mm to a couple of cm thickness. This silt is known to negatively affect recharge from floods (CRERAR et al. 1988). While infiltration rates in the alluvium can reach more than 1 cm/hour in the absence of silt layers, silt may reduce infiltration dramatically.
According to chemical & isotope research indirect recharge is indicated from the 9000 km^2 in the upper Kuiseb area (KUELLS & HEIDBUECHEL 2006) and the water at *Gobabeb, Homeb and Swartbank* represents a mixture of
a) recharge from (extremely large) floods and
b) the inflow from sections that carry the fingerprint of (isotopically) “heavier” water recharged further upstream.
The groundwater at the settlements *Homeb, Soetrivier, Klipneus and Swartbank* does not show strong temporal changes as a direct result of flood events.

While recharge from transmission losses is estimated with 1.5 Mm^3 (KUELLS & HEIDBUECHEL 2006), direct recharge rates have been estimated to reach at least 0.1 to 1 mm/year (DE VRIES & SIMMERS 2002). **The size of the basin creates a Groundwater-recharge of 2.5 x 10^6 m^3 / a (for the upper Kuiseb).**

In the Lower Kuiseb Dune Area (Kuiseb-down stream area) –model, according to findings of transmission loss measurements by KUELLS & HEIDBUECHEL (2006), *low water tables appear in the upper part and very high water tables in the lower part of the area*. The assumption that a high water table reduces transmission losses even in arid regions can be supported by this.

^{14}C ages in Kuiseb Delta indicate that *most of the Groundwater is recent (*KUELLS & HEIDBUECHEL 2006).
BGR (1998/Vol 7) underlined, that the Groundwater-table-measurements in some parts of the palaeochannels and near the present Kuiseb River had to be viewed as a momentary picture of a continual natural drainage of the aquifer, which owing to its low permeability may be assumed to occur very slowly. ^{14}C ages indicated that GW in some palaeochannels was recharged about 4000 years ago by infiltration of river water. Distinctly younger ages in other palaeochannels (1000 to 2000 a) lead to the conclusion that water can infiltrate into the Groundwater-system from the active Kuiseb River. The places where the palaeochannels intersect the Kuiseb River are potential areas for infiltration, especially in the area west of *Swartbank*.

There are springs at numerous places along the coast and at the lagoon at Sandwich Harbour. According to BGR (1998/Vol 7) their amounts of discharge had not yet been estimated.
Area-wide groundwater-recharge now or earlier is excluded by BGR (1998/Vol 7). Groundwater-flow in the palaeochannels can be estimated from the hydraulic gradients and permeabilities. The value of 0.42 Mm^3/a for inflow along the model boundaries is relatively low.

According to the **BGR (1998/Vol 7)-model** for the Lower Kuiseb area the groundwater-balance is governed by the inflow and outflow at the boundaries of the system. Inflow across the eastern model boundary amounts to 0.42 Mm^3/a via the Kuiseb River and different palaeochannels, determined by the local gradients and hydraulic conductivity. Outflow into the Atlantic at the western model boundary amounts to 0.42 Mm^3/a.
According to that study, there is little effect of an assumed well field on groundwater-flow in the system over a simulated period of 30 years. The outflow of 0.42 Mm^3/a is reduced by a groundwater-abstraction of 5.1 Mm^3/a by approx. 5 % to approx. 0.40 Mm^3/a after a simulated period of 30 years.
Owing to the unfavourable hydraulic conditions indicated by the low permeability values, the daily abstraction rates per well were limited to about 140 m^3. After about 25 years the water table in the middle of the modelled area and at the southern edge of the well field has been lowered down to the base of the aquifer. To maintain production, the abstraction rate would have to be reduced after 20 years to 4.5 Mm^3/a and after 25 years to 3.8 Mm^3/a. Assuming a minimum lowering of 5 m, the cone of depression progressively expands to about 100 km^2 of the Kuiseb Dune area.
According to a NamWater-Report (1997) recharge to the Lower Kuiseb Aquifers is dependent on runoff events and subsurface base flow. After the 1997 floods recharge to all the aquifers was recorded. Water levels in the Swartbank and Rooibank A areas increased by an average of 2.23 m and in the Dorop South and Rooibank B areas by 0.41 m and 0.5 m respectively. From recharge calculations approx. 15 Mm^3 of water infiltrated into the Swartbank and Rooibank A areas during runoff. **The safe yield of the Swartbank/ Rooibank A Aquifer is 3.3 Mm^3/a.**
An estimated 5.6 Mm^3 recharged into the Dorop South and Rooibank B areas. The safe yield of the Dorop South/ Rooibank B Aquifer in a time of minimum or no recharge from surface flow is 0.99 Mm^3/a as opposed to 2.0 Mm^3/a for the long-term sustainable yield which includes periodic recharge events.

According to NamWater (2001) based on **abstraction and change in water level calculations** for the Rooibank B and Dorop South areas between 1993 and 2000, **<u>the combined recharge for the Delta Aquifer is estimated in the order of 2.03 Mm^3/a.</u>**
Due to extensive silt layers found in the aquifers infiltration over the Swartbank and Rooibank A areas have a definite delayed time of approx. 6 months. A delayed time in infiltration is also inferred for the Rooibank B area.

The most recent available figures concerning the total sustainable yield of the Kuiseb according to a numerical groundwater flow model in NamWater (2001/Annex 6): the sustainable yield of the active Kuiseb is 4.9 Mm^3/a plus 2.5 Mm^3/a of the Kuiseb Delta (Rooibank & Dorop South) brings <u>the total sustainable yield of the Kuiseb to 7.4 Mm^3/a.</u>
Including the environmental demand of 0.8 Mm^3/a into the equation, it can be concluded **that the sustainable yield for the active Kuiseb between Swartbank and the Delta is in the order of <u>7 Mm^3/a</u>.**

2.4 Future water requirements for mining activities in the Kuiseb Basin

Possible mineral deposits that may become attractive for mining development in the future (apart from the currently operating mines/ Annex 7), which would have an impact on water requirements to be satisfied in the Kuiseb Basin, are the following:

1. Starting from 2012 *Reptile Uranium (Deep Yellow-Company)* want to abstract 5 Mm^3/a for Uranium-Calcrete mining in the Lower Kuiseb/ Gobabeb region (oral information from Dr. R. Ellmies BGR/ GSN)

2. The Map in Annex 8, received from GSN (Mrs. Filadelphia Mbingeneeko) shows the current state of mineral exploration (mainly Uranium and Copper Mining) along the Kuiseb River, which will require large quantities of water once exploitation takes place. According to the EPL Nos, these mining exploration areas are overlapping and there could be several reasons for that, e.g that the companies applied for different commodities and that could be a case whereby one company is exploring for base metals whereas the other company might be exploring for uranium.

2.5 Concise description concerning health of groundwater resources and the threats thereto, including quality and pollution of these waters, in order to devise control, protection and remedial measures

2.5.1 Groundwater Quality and Pollution

The Groundwater-quality in the Kuiseb Basin depends on the recharge and on the geologic conditions. There is a strong contrast in lithology between the area north and south of the Upper Kuiseb. In the northern part schist is the dominant rock, a fractured aquifer with small storage volumes and low transmissivity. These characteristics are also reflected in the hydrogeology and hydrochemistry:
The northern part has low yields and a lower Groundwater-quality due to high salinity. This water is mixed into the Groundwater of the alluvium most probably at *Gobabeb* (KUELLS & HEIDBUECHEL 2006), where the fresh Groundwater is underlain by brackish Groundwater, which may stem from this diffuse recharge.
The Groundwater-Resources in the Upper part are of lower quality in the northern part and of higher quality in the southern part. Also the yield is higher as quartzite represents a better fractured aquifer. The Groundwater-quality and yield decreases towards the west/downstream due to the reduction of rainfall & recharge.
The alluvium represents an exception: In the alluvial bodies the Groundwater-quality is generally better ~600 uS/cm compared to 1500-2500 (and more) uS/cm in the rock. The sustainability downstream increases related to 2 factors:

a) the basin area and the runoff production potential is getting higher until transmission losses revert this trend
b) there is also a constant seepage of Groundwater-recharge in higher sections of the alluvium.

Both processes, crucial for the estimation of Groundwater-recharge in arid environments, can be observed and estimated based on stable isotope data. A third component has been described that is produced by diffuse recharge. In the Kuiseb basin this component rather deteriorates the Groundwater quality due to its salinity.

The most intensive study on Groundwater-quality in the Lower Kuiseb area has been done by BGR (1995/Vol D-I):
The overall mineralization of the Groundwater varies to a large extent. Low mineralized waters of less than 250 mg/l are found. Highly mineralized Groundwater occurs near the coast.
The mineralization of the Groundwater in the active Kuiseb and Kuiseb south subareas is mainly caused by three factors:

- mineralization of the Kuiseb floodwaters
- mineralization of the floodwaters of the northern tributaries to the lower Kuiseb river
- evapotranspiration and solution during infiltration into the active Kuiseb aquifers.

The ephemeral floods reaching the lower Kuiseb river from the Khomas Highlands carry beside their sediment load of up to 4500 mg/l also a dissolved mineralization load (TDS) of up to > 500 mg/l, on average around 200 mg/l.
In 1993/94 the average TDS was at 1450, 600 and 950 mg/l at Klipneus, Swartbank and Rooibank A (BGR 1995/Vol D-I & BGR 1998/Vol D-II).

Very rarely floods from the northern tributaries (as Soutrivier and Aussinanis River) join the lower Kuiseb River as sheet flows cover the sodium chloride and calcium sulphate (gypsum) crusts of the Stone Namib, these waters are becoming highly mineralized. A floodwater at the Aussinanis confluence with the Kuiseb River was determined with a TDS-value of 5375 mg/l (1976), with 1700 mg/l of sulphate and 1670 mg/l of chloride ions (BLOM 1978).

The waters at the lower end of the mineralization scale belong to the Ca-Mg-HCO_3 Type, with up to 20 meq% Na-K-SO_4-Cl. With higher mineralization, the Na and K portion increases up to 70 meq% and the Cl/ SO_4 portion up to more than 90 meq%.

The evapotranspiration of Groundwater from the active Kuiseb River aquifers is also supposed to be a considerable factor of increasing the salinity.
While BGR (1995/Vol D-I) assumes, that due to the remarkable lowering of the Groundwater-table in the last 30 years this factor should have diminished to a large extent, MUINJO (1998) states that salinity has increased due to evapotranspiration of groundwater from the Kuiseb river.

In the Kuiseb South Subarea, with a mean Groundwater-table in the dune valleys in excess of 40 m below surface and under the dunes some 100 m below surface, and without vegetation, the evapotranspiration effects should be minimal. On the other hand the very slow Groundwater-movement in that area facilitates the enrichment through solution of salts from the aquifer (BGR 1995/Vol D-I).

In the Coastal Subarea, especially at the lowlands near sea level, the Groundwater-table is over larger areas relatively shallow, with 1 to 3 m below the surface. Here, additional to sea water intrusion, also the evaporation effect is also supposed to be relevant on increasing the overall salinity.
The overall salinity as well as chemical composition of Groundwater respectively has been compiled in Annexes A 6 and B 3 & B 4 of the Borehole Data Bank (BGR 1995/Vol D-I).

The considerable variations in the Groundwater-quality within the individual compartments of the Active Kuiseb subarea let one suppose, that they do not constitute homogenous aquifers. On the contrary it is a question of separate Groundwater compounds with differentiated Groundwater-bodies.
Such hydro-chemical differentiations, including **a classification for human consumption and health threats**, are given for the different palaeochannels of the Kuiseb South subarea in BGR (1995/Vol D-I/p.91-102).

2.6 Significant interdependencies between specific groundwater and surface water sources

Interdependencies between groundwater and surface water sources are given in terms of recharge, since recharge to the alluvial aquifers occurs mainly via vertical infiltration of runoff down the present day Kuiseb river and from through-flow within the alluvial aquifers, mainly during ephemeral flash floods (see Chapter “Recharge dynamics and rates” on page 11).

KUELLS & HEIDBUECHEL (2006) implemented an interaction of surface water and groundwater within a DAFLOW / MODFLOW-model for the Kuiseb area [using a coupled model from JOBSON &

HARBAUGH (1999)] by a seepage term which consists of the hydraulic conductivity of the streambed, the difference between the aquifer head and the river stage and the width of the stream bed at a certain discharge. Streamflow routing (with & without seepage to groundwater), return flow (out of the aquifer) and transmission losses (into the aquifer) were simulated, including pumping wells to adjust the model to the real situation.

B 7. Impacts on Groundwater resources of land use such as urbanisation and (alien) vegetation

Owing to the high evaporation rates, rain in the desert areas does not contribute to groundwater recharge. The coastal fog and rare rainfall however are sufficient for a flora and fauna that have adapted to these hyper-arid conditions. Vegetation is sparse within the dune field of the *Namib Sand Sea* (south of the Kuiseb) but a few fog-dependent, endemic plant species, such as *Stipagrostis sabulicola* & *Trianthema hereroensis* are found (SHANYENGANA 1997).

North of the Kuiseb within the *Namib plains* (a deflation surface with a thin layer of coarse sand & gravel, broken in places by granitic inselbergs and low kopies) calcrete, gypcrete & shallow suboutcrops of metamorphic & granitic basement lithologies underlie the gravel plains. In general these plains are devoid of vegetation supporting *lichen*, a few *dwarf shrubs* and *acacias*. *Welwitschia mirabilis* are found in a limited number of localities. *Grasses*, particularly *Stipagrostis species* are common, proliferating after rare rainfall events (SHANYENGANA 1997).
Riverine vegetation is mainly consisting of 4 species: *Anatrees (Faidherbia albida), Camel Thorn (Acacia arioloba), False Ebony (Euclea pseudobenus), Tamarix (Tamarix usneoides)* (BATE & WALKER 1993).

A high degree of uncertainty exists regarding the **evapotranspiration** by trees and vegetation that is found in the Lower Kuiseb River.
BLOM (1978) calculated an evapotranspiration loss of 0.24 m/a over the whole active Kuiseb River plain. Incorporating this value over an area 23 km X 1 km with an average storativity of 15 %, an evapotranspiration volume of **0.83 Mm^3/a** is calculated.

Experiments carried out at Gobabeb in 1980 by BATE & WALKER concluded that vegetation in the river at Gobabeb uses probably between 15 - 20 % of the water in the aquifer per year. Due to the fact that these values are influenced by the storage capacity of the aquifer, over-estimations of evapotranspiration will be calculated for aquifers with high storage capacities. The stored reserves in the Lower Kuiseb, that is in the order of 150 Mm^3 between Swartbank to Rooibank, will for instance yield an estimated loss to evapotranspiration for this area of approximately **24 Mm^3/a**, which is far higher than the sustainable yield of the aquifer.

After SONNTAG (1985/ cited in NamWater 2001), the evapotranspiration loss in this sandy aquifer with its water table in place between 8 and 16 m below ground must be much less. He published a graph, according to which in arid regions, evaporation from a 10 m deep water table in a sandy aquifer amounts to around 0.3 mm/annum. Calculating over an area of 23 km X 1 km, this value indicates an evapotranspiration loss from the water table of only **70 000 m^3/a**, which seems to be rather low.

Although the vegetation is certainly influenced by prevailing climatic conditions, the availability of groundwater probably has the most pronounced effect on the habitat of the different species along the ephemeral rivers. THERON et al. (1980) investigated the vegetation of the lower Kuiseb River valley upstream of Rooibank. They compiled a map and distinguished 14 different communities with the *Acacia albida* and *Acacia erioloba* communities as the most important. A total of 40 variations were distinguished. Four additional units, consisting mainly of dead herbaceous species were mapped between *Gobabeb* and *Rooibank*.

The maintenance of this vegetation is not only essential to the Kuiseb River ecosystem as a whole, but the vegetation along this linear oasis acts as a barrier checking the northwards movement of the *Namib Sand Sea*. The dune & inter-dune valleys are very sparsely vegetated. Along the Koichab and Omaruru river valleys, the vegetation is less dense compared with the Kuiseb river, apart from the area which is now being impounded by the OMDEL Dam.

Another comprehensive study on vegetation & ecology has been done by HUNTLEY (1985), where interdependencies of groundwater & vegetation can be studied (see also chapter B 2 & B 7).

2.7 Inputs for the ecologist in the team to estimate ecological water requirements

The Kuiseb plain is considered a linear oasis or a green belt in the desert. While in the desert itself there is nearly no vegetation, the river plain maintains a woodland vegetation, normally composed of Anaboom, Camel thorn, Wild tamarisk, Ebony tree, Mustard tree and Sycamore fig. Famous is the Nara melon, that is covering small sand dunes within the river bed and also its southern flank (BGR 1995/Vol D-I).

BLOM (1978) mentions that downstream of Rooibank the tree vegetation with a few exceptions disappears altogether from the river plain.
The vegetation cover depends for their survival on the infrequent floods and on the subsurface water flow. The *reduction of the vegetation cover* reported on the last decades, may be caused by different effects:
A very important one has been certainly the *lowering of the Groundwater-table due to the intensive Groundwater-abstractions in the lower Kuiseb valley* (BGR 1995/Vol D-I).
But also the domestic stocks of the native Topnaar communities may have contributed so far, because their goats feed especially on new sprouts and young trees, hampering by these new tree generations to grow up.

One of the most comprehensive studies on vegetation & ecology for the Kuiseb environment has been conducted by HUNTLEY (1985). During that investigation the Kuiseb Basin was divided into hydrological/ ecological compartments within and between each of which the rates and directions of water transfers and the factors influencing or influenced by these flows could be studied.

According to such studies the consequences of the increased use of the water resources of the Kuiseb basin were believed to cause a lowering of the water table which would result in:

- the death of the dense acacia woodland which forms a linear oasis across the desert
- the unhindered northward advance of dunes from the Namib Sand Sea
- the termination of subsurface flow of freshwater from the Kuiseb to Sandwich Lagoon
- the depletion of drought reserves for plains game and Topnaar domestic stock through the loss of the acacia woodland and associated vegetation
- and ultimately the siltation of Walvis Bay Lagoon.

The overriding conclusion that could be drawn from those studies conducted within this Kuiseb Environmental Project was that the entire ecosystem is extremely dynamic, undergoing unusually large fluctuations in all climatic, geomorphological, hydrological and ecological processes. Water is unquestionably the principal driving force in the Kuiseb environment and changes to the volume, rate and directions of flows within the system would have major consequences. At that time man-induced changes to the hydrology of the Kuiseb basin had not been demonstrated to have influenced geomorphological or ecological processes within the area.

Water supplied from the nearby Omaruru River caused a considerable reduction in the rate of water abstraction from the Lower Kuiseb, following an initial threefold-increase from 1974 to 1977. This undoubtedly averted major changes being recorded during HUNTLEY's study (1985). The detailed baselines established during that project provide a benchmark against which changes can be measured in the long term, particularly during the establishment of a basin water management plan.
According to limited unofficial experiments carried out by the Laboratory and Research Division within NamWater (NamWater 2001), **a water demand for a big tree could be as high as 180 m^3/a**, depending on the availability of water and climate. To apply this value, the number of big trees in the Kuiseb River must be known and an investigation on the demand of each species in the Kuiseb River must be investigated. In NAMWATER (2001) it was assumed, that water is always available in the alluvium and a density of between 5 and 8 trees per hectare exists. The total area that could be covered by trees in the Kuiseb River between Swartbank and Rooibank was digitised to obtain the area and estimated at 450 hectare. This means that between 2 250 and 3 600 trees are located in the river between Swartbank and Rooibank. **This means that the water demand from the trees in this part of the aquifer based on the above assumptions is estimated to be between 0.4 Mm^3/a and 0.65 Mm^3/a.**

2.8 Gaps and shortcomings in information, knowledge and measures

Information gaps exist regarding the entire Kuiseb Basin. There are much more Groundwater-research-data available in MAWF/ DWAF for the downstream area than for the upstream area.

2.9 Scope-level vulnerability assessment

List of previous work and geohydrological inputs for scope-level assessment of vulnerability of groundwater to contamination from spillage of harmful substances.

1. **BGR (1998)**: German-Namibian Groundwater Exploration Project – Technical Cooperation Project No.: 89.2034.0 – Follow Up Report **Vol.7** – Kuiseb Dune Area/ Assessment of the Groundwater Potential (by G. SCHMIDT)
2. **CHRISTELIS, G. & STRUCKMEIER, W. (Ed.) (2001)**: Groundwater in Namibia, an explanation to the Hydrogeological Map [HYMNAM (Hydrogeological Map of Namibia 2001]. 1st edition, BGR & DWA & GSN, Windhoek 2001.

According to HYMNAM (Hydrogeological Map of Namibia 2001) the following differentiations for the ***vulnerability of groundwater-resources and risk of pollution,*** assessed on the basis of aquifer type, GW-flow, depth to GW and annual recharge are being made:

High: Along the Kuiseb river valley, from approx. 50 km east of Gobabeb to the coast

Moderate: Area A: upper catchment area from the Kuiseb start west of Windhoek to approx. Rostockberg/ Sandsteenberg area
Area B: Kuiseb Delta: Gobabeb area to the coast

Rather low: From approx. Rostockberg/ Sandsteenberg area to the coast (north & south of "Moderate Area B"

3 First cycle and future action plans

3.1 Preparation of the action plans by providing the necessary expert inputs for these plans to the Team Coordinator

Owing to the favourable amount of data for the river area the results for the approximation of Groundwater-recharge from flash floods in the Kuiseb river may be viewed as reliable and thus the results of the (BGR 1998/Vol 7)-model may also be viewed as relatively good.
According to that model & report as well as NamWater (2001) Groundwater-production between *Swartbank* and *Rooibank* (and further west) must be restricted in the future to avoid completely draining the system by Groundwater-mining.

Improvement in the reliability of recharge rates from the flash floods determined by modelling can be attained only by more closely monitoring the outflow and Groundwater-table data and inclusion of studies of the unsaturated soil zone. These measures will require considerable effort, but will provide a finely tuned Groundwater-balance. They will not provide predictions that can be used for water management, however, because future rainfall rates are not known.

According to the (BGR 1998/Vol 7)-model the calculations for the assumed well field in the dunes area indicate a lowering of the water table that would occur with a horizontal drainage system. The operations lifetime would be 20-30 years in the most favourable case. In the case of conventional abstraction rates from individual wells a large number of wells each with a low pumping rate would be necessary in order to avoid lowering the water table too much. Taking the results obtained for the palaeochannels into consideration, the simulated well field is in the last possible, relatively large area. This location has disadvantages, however, because this well field would be

- below the level of the flow of brackish water in a palaeochannel (01)
- the furthest distance within the region from the available electricity supply and roads
- in an area with a relatively low degree of hydrogeological exploration with the attendant uncertainties in the data on Groundwater-levels and depth to the base of the aquifer.

Groundwater exploration in the Kuiseb Dune area has provided information with which the description of the Groundwater-system as a whole could be improved and made it possible to model the southern part of the study for the first time (BGR 1998/Vol 7). The data base is sufficient to estimate the amount of groundwater in the system and the possibilities for Groundwater management.
It must be expected that considerable effort would be required to further improve the already available information and that these efforts would not be justified by usefulness of the results.
A cost-benefit analysis indicates that the only alternative for securing a long-term water supply for the coastal region would be a **desalination plant** (GKW, PARKMAN, BICON 1996/ BGR 2000/ Vol.3), that is currently under construction (2008).

3.2 Identification of medium and long-term basin management and improvement plans

An assessment of recharge from runoff to the Lower Kuiseb Aquifer is greatly dependent on the availability of accurately interpreted hydrological data. All efforts should be made according to NamWater (1998) to maintain existing gauging stations at Gobabeb and Rooibank (at least) and to record and evaluate runoff data on a regular basis.
NamWater (1998) suggests concerning the assessment of recharge & sustainable yield

- the collation of existing data from previous investigations to determine more accurately aquifer boundaries, boundary conditions, dynamics of natural recharge and discharge

- proper conceptualization of the aquifer system for the further application in numerical Groundwater- flow models, which can be applied for management purposes, if realistically conceptualized and constructed.

Concerning medium and long-term basin management and improvement plans the following is recommended for the Erongo Region by WATER & WASTE MANAGEMENT TECHNICAL ADVISORY COMMITTEE/ WWM TAC of THE CHAMBER OF MINES OF NAMIBIA (unpublished meeting minutes 02/2008 & 03/2008):

Because of its value and importance to sustain life, water usage needs to be managed, especially when used for non-domestic purposes in such large volumes as proposed by the uranium mines. It is thus important to have an overall governing Water Strategy Framework which should address and regulate all aspects of water usage of the uranium mines. Before preparing any Strategy on water usage and the management thereof, there are water-related objectives which must be addressed as these have a significant influence on any action proposed by the WWM TAC. These strategic issues are the following:

1. **Clarify the <u>roles and responsibility</u> of the different role players so that it is clearly understood who will take responsibility for enforcing what legislation, who will do the permitting, who and what will be monitored, etc.**

    - What are the roles (e.g. management, permitting, monitoring) of the various government ministries (DWAF, MET and MME), the Erongo Regional Council and the Water Utility companies such as NamWater?
    - How do the different organisations interact (National, regional, local government, Parastatals and private water utilities)?
    - How can the CoM influence / improve the performance of some Ministries / Utilities?
    - Is it possible for private Water Utilities to be formed and to compete with NamWater?
    - If water is to be supplied to the mines by a private water utility and not NamWater, what is the role of this private utility and how will its operations and performance be monitored?
    - Understand the NamWater organisation structure so that relationships can be built and actions put in place to ensure that NamWater is able to provide a reliable and quality service to bulk water users. This includes adequate and trained staff, as well as financial backing, to affect immediate repairs and improve on maintenance.

2. **Establish <u>the current status and sustainability</u> of all groundwater resources at the coast, and not only the Kuiseb and Omdel, so as to establish a broader understanding of the groundwater resources available and of the opportunities and constraints associated with this resource.**

    - The current status of all the available <u>groundwater resources</u> in the Central Namib should be determined. We need to understand if these underground aquifers are linked to each other as cross-flow may influence decisions around extraction? We also need to understand the rates at which other aquifers are recharged and how much is being extracted from them. The end product should be data that can be made available to bulk users and water management agencies and includes water volumes (total abstractable reserves, abstraction and recharge), sustainability of aquifers, water quality, background radiation, etc.
    - Identify alternative options for potable water (e.g. desalination, improved recycling and treatment of industrial water).
    - Ensure that NamWater has a clear Policy that outlines how the groundwater resource will be utilised, describes their commitment towards desalination and explain how desalination will be incorporated into their water management plan.

- Once the status of the ground water aquifers are understood, we need to understand how water users are managing their water. Ideally, any utility (NamWater, private utility or bulk user) that is granted permission, by DWAF, to take water from a ground water resource must prepare and present a Water Master Plan to DWAF who in turn must have a Water Master Plan for the Central Namib. This will facilitate monitoring and management of the sustainable use of water.
- We also need to ensure that water users in the Central Namib have valid abstraction licenses from DWAF and we need to understand what the conditions of those licenses are (e.g. how much can be extracted and for what length of time).

3. The <u>socio-economic environment</u> and the water needs of all users in the region must be understood.

- The role of <u>local communities</u> in the construction, management, operation and / or maintenance of water supplies, as well as any potential social responsibility or assistance of the uranium mines in general or of a specific mine (e.g. Rössing Foundation) towards the local community in their mining area, should be clearly spelled out.
- Conduct a socio-economic study that profiles current water-users, their needs and expected future needs and identifies potential future users (e.g. eco-tourism, heavy industry in Walvis Bay etc) and their needs.
- Develop a stakeholder database (including their expectations, roles, etc) to ensure that Interested and Affected Parties (I&APs) are included in the development of a regional water strategy. This will include national, regional and local stakeholders other than government departments and bulk users.
- Identify existing and potential water *fora* and committees and understand their mandates and goals (e.g. the Kuiseb Basin Management Committee-KBMC and Omaruru BMC) as well as in the other basins, are the ideal platform to address water related issues with the community and this avenue should be utilised by other water users (e.g. mines and utilities).

4. Strengthen the <u>legal framework</u> pertaining to the use, conservation and management of surface and ground water.

- DWAF to complete the Water Quality (potable and effluent) Regulations being developed in terms of the Water Resources Management Act 2004 and ensure that the regulations are passed so that the Water Resources Management Act 2004 can be enacted.
- Understand the status of the Integrated Pollution Control and Waste Management Bill and work through the issues that are preventing it from being promulgated.
- MET and DWAF to develop regulations for the Integrated Pollution Control and Waste Management Bill and submit these to Cabinet with the Bill. The Regulations should address the “polluter pays principle” to discourage indiscriminate dumping.
- MET and DWAF to finalise the Regulations / Minimum Requirements on the handling, classification, transporting and safe disposal of hazardous waste.

Issues that need to be addressed by all bulk water users:

If water in the Erongo Region is to be used and disposed of in a sustainable manner, an integrated Water and Waste Management Strategy will be required for the region. All bulk water users will need to align themselves with this strategy. The issues that will need to be considered in such a strategy are listed below and discussed in more detail in Table 1.

1. Develop a <u>Water Conservation & Demand Management Plan</u>, to ensure the optimum use of water.

- Water conservation is inter-alia defined at "*the minimisation of loss or waste, the preservation, care and protection of water resources and the efficient and effective use of water*".

- Demand management is inter-alia defined as "*the adaptation and implementation of a strategy (policy and initiatives) by an institution to influence the water demand and usage of water to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability*".

2. **Contribute to the protection of the environment, ecology and natural water resources of the Erongo region by preventing pollution arising from the discharge of liquid effluent and solid waste.**

3. **Establish an information management and monitoring system to improve communication between bulk users and stakeholders and to regulate the use of data.**

4. **Implement a Liquid Waste Management Plan to promote the re-use of treated effluent and reduce the risk of groundwater pollution.**

5. **Implement a Solid Waste Management Plan to coordinate waste collection, transportation and disposal activities.**

6. **Establish a Disaster Management Plan to minimise the risk of groundwater pollution during unforeseen situations.**

Table 1: Table of actions that will need to be put in place if water management issues are to be addressed

Responsibility	Actions
1. Develop a Water Conservation & Demand Management Plan, ensuring the optimum use of water	
DWAF & Water Utility	Ensure that all Water Utilities (e.g. NamWater) have a valid water abstraction and effluent discharge permits for the supply of water from each water resource at the coast and for the discharge of the treated effluent back into the environment (land, fresh water or marine). Audit compliance annually.
DWAF & Bulk users	Ensure that bulk users (e.g. mine) abstracting water directly from a groundwater source and not via a Water Utility have a valid water abstraction and effluent discharge permits.
Water Utilities / DWAF	Any Water Utility supplying water to the mines directly to have the necessary water abstraction and effluent discharge permits from DWAF.
MET / DWAF	Develop strategies to ensure that the use and management of the water resources at the coast does not destroy or damage the local ecosystems and biodiversity. These strategies to be shared with all bulk water users and be updated every 5 years.
NamWater (& other water utilities)	Re-evaluate and annually update its Water Master Plan for the Region, including the sustainable yield calculations of all natural water resources at the coast. Water utilities to communicate this plan to their users.

Responsibility	Actions
Bulk users	Bulk water users to draft a site specific Water Conservation and Demand Management (WC&DM) Plan, which must be submitted to DWAF. Specific water conservation objectives should be set and be reviewed at least every 5 years to ensure targets are being achieved and are driving continuous improvement.
DWAF / CoM	DWAF to monitor the mines against their consumption targets to ensure efficient and effective use of water. This to include the development and monitoring of a water efficiency rating / benchmark system, to be monitored by the CoM.
NamWater / DWAF	Investigate the development of incentives and rewards for mines achieving the water efficiency rating and for WC & DM initiatives.
NamWater / Bulk users (CBWUF)	Bulk water users as part of their WC&DM Plan to in writing via the CBWUF submit a 10-year water demand projection to NamWater, highlighting the expected timeline for consumption. Projections to be updated annually.
NamWater / Bulk Users / Mines	Bulk water users and mines receiving water from NamWater to conclude and sign a Water Supply Agreement with NamWater, highlighting the term and conditions under which such service are provided by NamWater.
NamWater	NamWater to draft a clear Policy on how it will manage water distribution to all of its bulk users in the event of reduced water availability at the coast (as a result of damage / failure of infrastructure, natural disasters or if the sustainable yield is exceeded).
Mines	Ensure the long-term sustainability of groundwater resources by supporting the establishment of a seawater desalination plant in the Central Namib area.
Mines	Educate and create awareness on WC & DM issues within the mine by introducing an internal training programme on WC & DM aspects for employees and contractors.
2. Protection of the environment from pollution	
Mines / DWAF	All mines to develop a ground water monitoring programme to prove that they are not polluting the ground water. DWAF to review and endorse the ground water monitoring programmes and monitor results regularly.
Mines / DWAF	Develop site specific effluent quality discharge standards against which compliance can be measured.
Mines	Regular (minimum of monthly) effluent discharge monitoring to be done to ensure that effluent discharge standards are being met. Ensure zero discharge of effluent to the environment unless in possession of a valid permit and unless discharge standards are being met.
Mines or Water utilities	A valid discharge permit should also be obtained in the case of desalination where brine is discharged back into the sea.
Mines	Each mine to prepare and submit a site specific Mine closure plan (including decommissioning and rehabilitation) to the relevant Ministries for approval (MET, MME, DWAF, MOHSS). The plan shall be updated at least every 3 years.
CoM	CoM to keep copies of all Mine closure Plans. Someone needs to monitor Mine closure Plans meet the required standard and that mines are complying. If regulators are not performing this task we need to discuss what the best way forward is to ensure industry compliance.

Responsibility	Actions
3. Establish an information management and monitoring system to improve communication between stakeholders and to regulate the use of data	
Mines / BMC	Bulk users and mines to elect a representative from amongst themselves to attend Basin Management Committee (BMC) meetings and share data with all BMC members.
Mines / CBWUF	Bulk water users (including the mines) to attend the Coastal Bulk Water Users Forum (CBWUF) meetings and share data with all CBWUF members.
Mines / Bulk users	Share non-confidential data and expertise gained via the various water programmes within the respective mine / utility / town with external groups / Govt. / to increase awareness of water issues amongst all at the coast on the value and conservation of water.
CoM	Develop a database and / or library of knowledge, information and case studies and ensure easy access to all interested parties.
4. All bulk water users to implement a Liquid Waste Management Plan to promote the re-use of treated effluent and reduce the risk of groundwater pollution	
DWAF / Bulk water users	Domestic effluent - Ensure that all bulk users have a properly designed and functional Sewage Treatment Plant and a valid Sewage Discharge Permit. This will also apply for the sewage disposal from ablutions and related facilities at mines.
Mines / industrial bulk users (Namport)	Industrial effluent - All bulk water users producing industrial effluent to ensure zero discharge of effluent to the environment (water or land) unless in possession of a valid discharge permit and unless discharge standards are being met.
Mines / industrial bulk users (Namport)	All bulk water users producing industrial effluent to have properly designed and functional facilities to ensure that industrial effluent is not released into the environment. This includes but is not limited to: Effluent treatment plants, Pollution control dams, Evaporation ponds, Tailings storage facilities, Storm water control facilities, Recycling facilities.
DWAF	DWAF to control and monitor the discharge permits of all Mines and bulk users to ensure compliance and timely renewal thereof.
5. All mines and towns to implement a Solid Waste Management Plan to coordinate waste collection, transportation and disposal activities and reduce the risk of environmental pollution	
Mines / Municipalities / Industries	Mines, Municipalities and Namport (Bulk users) to draw up an individual site specific Solid Waste Management Plan, addressing the handling, storage and safe disposal of all types of waste. The plans should also address waste minimisation (reduction, recycling and reusing).
Mines	Investigate the possible establishment of a centralised hazardous waste disposal facility to minimise the risks associated with the transport and disposal of hazardous waste (non radioactive).

Responsibility	Actions
Mines	Supply various ministries (MOHSS, MME, Met and DWAF) with outline of how radioactive waste will be managed.
Mines	Mines to individually comply with and ratify the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste.
Mines	Investigate the possible re-use of waste oil in burners to minimise on the dumping of waste oil and / or purchase of new oil / diesel for burner / power generation applications.
Mines / Municipalities / Industries	All domestic and hazardous solid waste to be removed from the mines, Municipalities and Namport on a regular basis and be disposed of at approved landfill sites or hazardous waste disposal facilities only.
CoM	A system of auditing the Mines for compliance, to be developed and implemented.
Line Ministry	In the absence of national legislation, towns to be audited by the relevant line Ministry
6. Each mine to establish a Disaster Management Plan to minimise the risk of groundwater pollution during unforeseen situations	
Bulk Users	All bulk users are to draft a Disaster Management Plan, which clearly outlines how spillages (potable water or effluent) will be contained during a disaster, early warning systems, crises reaction and intervention, public awareness, international assistance, etc.
Mines / CoM	All mines to submit their Spillage Disaster Management Plans to the CoM.

BMC	Basin Management Committee
CBWUF	Coastal Bulk Water Users Forum
CoM	Chamber of Mines
DWAF	Department of Water Affairs and Forestry
IAEA	International Atomic Energy Agency
HERS	CoM Health, Environment, Radiation and Safety Committee
MET	Ministry of Environment and Tourism
MME	Ministry of Mines and Energy
MLRGH	Ministry of local and regional government and housing
SEMP	Strategic Environmental Management Plan
WC & DM	Water Conservation and Demand Management
WRM Act	Water Resources Management Act
WWM TAC	Water and Waste Management Technical Advisory Committee