

mit ~~3757~~ 20500  
96/283

mi01a

REPUBLIC OF NAMIBIA  
Department of Water Affairs  
Windhoek

FEDERAL REPUBLIC OF GERMANY  
Federal Institute for  
Geosciences and Natural Resources  
Hannover

# TECHNICAL COOPERATION

PROJECT NO. 89.2034.0

## GERMAN-NAMIBIAN GROUNDWATER EXPLORATION PROJECT

### REPORTS ON HYDROGEOLOGICAL AND ISOTOPE HYDROLOGICAL INVESTIGATIONS

VOL. D-1

Groundwater Exploration in the Kuiseb Dune Area

Part 1: Text

---

**Bundesanstalt für Geowissenschaften  
und Rohstoffe**

---



REPUBLIC OF NAMIBIA  
Department  
of  
Water Affairs  
Windhoek

FEDERAL REPUBLIC OF GERMANY  
Federal Institute  
for  
Geosciences and Natural Resources  
Hannover

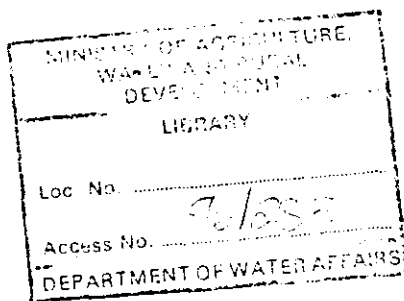
Technical Cooperation

Project No. 89.2034.0

GERMAN-NAMIBIAN GROUNDWATER EXPLORATION PROJECT

REPORTS ON HYDROGEOLOGICAL AND ISOTOPE  
HYDROLOGICAL INVESTIGATIONS

Volume D - 1



Groundwater Exploration in the Kuiseb Dune Area

Part 1 - Text

Authors: R. Lenz, H. Grobbelaar, M. Djama  
comissioned by: Federal Ministry for Economic  
Cooperation and Development ( BMZ )  
Date of issue: 11.8.1995  
Archives No : 113 840

CONTENTS :

<u>Part 1 - Text</u>		Page
SUMMARY.....		I
ACKNOWLEDGEMENTS.....		II
ABBREVIATIONS.....		X
1. INTRODUCTION.....		1
1.1 Water Supply at the Central West Coast.....		1
1.2 Historical Review on Groundwater Exploration in the Project Area.....		5
1.3 The German-Namibian Groundwater Exploration Project.....		8
2. PHYSIOGRAPHY .....		11
2.1 Locality.....		11
2.2 Topography.....		11
2.3 Climate.....		16
2.4 Vegetation.....		17
3. SURFACE WATER.....		18
3.1 Runoff.....		18
3.2 Ephemeral Rivers.....		18
3.2.1 Kuiseb River.....		18
3.2.2 Tsondab River.....		22
4. GEOLOGY.....		23
4.1 Basement.....		23
4.1.1 Depositional History.....		23
4.1.2 Basement Rocks in the project area.....		25
4.2 Paleo-Mesozoic.....		27
4.3 Cenozoic.....		27
4.3.1 Depositional History.....		27
4.3.1.1 Tsondab Sandstone Formation.....		30
4.3.1.2 Karpfenkliff Conglomerate Formation.....		30
4.3.1.3 Kamberg Calcrete Formation.....		31
4.3.1.4 Kuiseb Palaeochannel Fill.....		31
4.3.1.5 Sossus Sand Formation.....		34
4.3.2 Cenozoic Rocks in the project area.....		34
4.3.2.1 Active Kuiseb Subarea.....		36
4.3.2.2 Kuiseb South Subarea.....		36
4.3.2.3 Tsondab Subarea.....		42
4.3.2.4 Coast Subarea.....		44
4.3.2.4.1 Northern Part.....		44
4.3.2.4.2 Southern Part.....		47

	Page
<b>5. GEOHYDROLOGY.....</b>	<b>48</b>
5.1 Geohydrological behaviour of the rock units.....	48
5.2 Groundwater Subareas.....	50
5.2.1 Active Kuiseb Subarea.....	51
5.2.1.1 Natab - Aussinanis.....	53
5.2.1.2 Klipneus.....	53
5.2.1.3 Swartbank.....	54
5.2.1.4 Rooibank - A.....	58
5.2.1.5 Haob.....	60
5.2.1.6 B - Area.....	61
5.2.2 Kuiseb South Subarea.....	63
5.2.2.1 Palaeochannels.....	75
5.2.2.2 Tsondab Sandstone.....	81
5.2.3 Tsondab Subarea.....	83
5.2.4 Coast Subarea.....	85
5.2.4.1 Palaeochannels.....	85
5.2.4.2 Abstraction Problems.....	86
<b>6. GROUNDWATER QUALITY.....</b>	<b>87</b>
6.1 Origin of salinity.....	87
6.2 Regional distribution of groundwater salinity.....	88
6.2.1 Active Kuiseb Subarea.....	88
6.2.2 Kuiseb South Subarea.....	91
6.2.3 Quality variation in time.....	93
6.3 Classification for human consumption.....	100
6.3.1 Guidelines of the DWA.....	100
6.3.2 Classification of the groundwaters in the Kuiseb South Subarea.....	100
<b>7. BOREHOLE GEOPHYSICAL INVESTIGATION (H. Grobbelaar).....</b>	<b>102</b>
7.1 Introduction.....	102
7.2 Geophysical Logging.....	102
7.3 R-Series Logger.....	103
7.4 Gamma Logs.....	104
7.5 Water Conductivity.....	105
7.6 Temperature Log.....	107
7.7 Caliper.....	108
7.8 Borehole Resistivity Logs.....	109
7.9 Drilling Mud and Geophysical Borehole Logging.....	111
7.10 Borehole Geophysical Results obtained with the R-Series Logger in the Dune Area south of the Lower Kuiseb River.....	113

	Page
8. DATA COLLECTION.....	118
8.1 Borehole Data Bank.....	118
8.2 Sampling Programme.....	119
8.3 Test Drilling Programme.....	120
8.4 Ground Geophysics.....	123
9. RECOMENDATIONS FOR SMALL SCALE GROUNDWATER EXPLORATION.....	125
9.1 Basic requests.....	125
9.2 Exploration proposals.....	125
9.2.1 Kuiseb South Subarea.....	125
9.2.2 Tsondab Subarea.....	126
9.2.3 Coast Subarea.....	127
10. BIBLIOGRAPHY.....	128

FIGURES :

	Page
1.1 GNGEP - Location of Project Areas.....	III
1.2 Central Namib Regional State Water Scheme.....	2
1.3 Groundwater abstraction areas in the Lower Kuiseb River...3	
1.4 Regional geophysical survey with follow up drilling activities ( 1960 - 1980 ).....	7
1.5 Area covered by GNGEP airborne geophysics in 1992.....	9
2.1 GNGEP - survey area.....	12
2.2 Localities, river subdivisions & hardrock barriers at the Kuiseb River.....	13
3.1 Rainfall and runoff over the catchment area of the Kuiseb River.....	20
3.2 Catchment area of the Tsondab River.....	22
4.1 Damara - Orogen in Namibia.....	24
4.2 The Great Namib Sand Sea between Walvis Bay and Lüderitz..28	
4.3 Kuiseb palaeochannels.....	32
4.4 The Namib Desert at the westcoast of Southern Africa.....	35
4.5 Geological and geohydrological subareas.....	37
4.6 Erosional structures with a probably tectonical origin....	38
5.1 Groundwater compartments of the active Kuiseb river plain.	52
5.2 Swartbank - Drawdown of groundwater table in observation wells in relation to annual production, between 1978 and 1994.....	55

VII

	Page
5.3 Rooibank A - Drawdown of groundwater table in observation wells in relation to annual production, between 1985 and 1994.....	59
5.4 Former model of groundwater flow between Active Kuiseb and Kuiseb South subareas (vertical section).....	65
5.5 Former model of groundwater flow in palaeochannels in the Kuiseb South Subarea (regional map).....	66
5.6 Localization of vertical sections 1 - 4.....	70
5.7 Vertical Section 1 of Airborne EM Survey.....	71
5.8 Vertical Section 2 of Airborne EM Survey.....	72
5.9 Vertical Section 3 of Airborne EM Survey.....	73
5.10 Vertical Section 4 of Airborne EM Survey.....	74
6.1 Hydrochemical cluster of the main cation and anion groups.....	90
6.2 Klipneus - TDS changes between 1977 and 1984.....	94
6.3 Swartbank - TDS changes between 1971 and 1994.....	95
6.4 Rooibank A - TDS changes between 1970 and 1993.....	96
6.5 B-Area - TDS changes between 1963 and 1981.....	96
6.6 PCH # 3 - TDS changes between 1970 and 1994 .....	98
6.7 PCH # 4, # 5 - TDS changes between 1975 and 1993.....	98
6.8 PCH # 5, south of Rooibank - TDS changes between 1976 and 1994.....	99
7.1 Principle of a normal sonde.....	110
7.2 Positions of all newly drilled boreholes geophysically logged.....	114
7.3 Positions of all dune valleys, in which existing boreholes, that were logged, are located.....	115
8.1 Test Drilling and Aquifer Evaluation Programme.....	121
8.2 Time Domain Electromagnetic Survey.....	124
9.1 Exploration proposals in the Kuiseb South Subarea.....	127

TABLES :

1.1 Groundwater abstraction in the lower Kuiseb River.....	4
1.2 Water demand at the Central Namib Regional State Water Scheme - middle scenario -.....	5
1.3 Investigation activities for groundwater in the Kuiseb River valley and adjacent dune area.....	6
3.1 Mean runoff data for the Kuiseb River, 1960 - 1987.....	19
3.2 Maximum and minimum runoff data for the Kuiseb River, 1960 - 1987.....	21
4.1 Crystalline basement in the Kuiseb Dune Area.....	23
4.2 Lithostratigraphic units of the Cenozoic in the Kuiseb Dune Area.....	29

	Page
5.1 Active Kuiseb Subarea - groundwater parameters for Rooibank A, Swartbank and Klipneus.....	56
5.2 Active Kuiseb Subarea - groundwater reserves for Rooibank A, Swartbank and Klipneus.....	57
5.3 Groundwater reserves in the aquifer systems of the Kuiseb South Subarea.....	67
5.4 Hydraulic parameters of the sedimentary aquifers in the Kuiseb South Subarea.....	68
5.5 Groundwater reserves of the individual aquifers in the Kuiseb South Subarea.....	68
5.6 Groundwater seepage from the active Kuiseb River plain into the palaeochannels in 1993.....	69
5.7 Hydraulic parameters in PCH # 3.....	78
5.8 Hydraulic parameters in PCH # 5, southwest of Rooibank....	81
6.1 Total Dissolved Solids in the Active Kuiseb Subarea.....	89
6.2 Salinity in the individual aquifers.....	91
6.3 Mean values of cation and anion groups, in meq %, in the individual aquifers.....	92
6.4 Minimum and maximum values of cation/anion groups, in meq %, in the individual aquifers.....	92

## Part 2 - Annexures A

### A - Thematic Maps of the Project Area, scale 1 : 100.000

- A 1 - Borehole Locations
- A 2 - Ancient Drainage Systems >> Palaeochannels <<
- A 3 - Groundwater Contour Lines
- A 4 - Groundwater Reserves
- A 5 - Recharge Conditions and Aquifer Thickness
- A 6 - Groundwater Salinity (Total Dissolved Solids)
- A 7 - Groundwater Ages
- A 8 - Drawdown of Rest Water Level between 1972 and 1993  
Depth of Rest Water Level below ground, in 1993
- A 9 - Geological Map
- A10 - Contour Lines of Crystalline Basement

Part 3 - Annexures B + C

## B - Borehole Data Bank

- B 1.1 - 1.6 Equivalence of Project and DWA borehole numbers
- B 2.1 - 2.18 General Data and Geohydrological Data
  - Kuiseb South Subarea
  - Active Kuiseb Subarea
  - Coastal Subarea
- B 3.1 - 3.8 Data on Total Dissolved Solids and Isotope Ages
- B 4.1 - 4.4 Hydrochemical Analyses of Groundwater
- B 5.1 - 5.6 14 C Groundwater age determinations in 1992/95, by the project
- B 6.1 - 6.3 Trace elements in groundwater

## C - Test Drilling Program 1993/94

- C 1.1 Test Drilling Programme - General Data
- C 1.2 Test Drilling Programme - Geohydrological Data
- C 2 Legend to the Well Records
- C 3.1 - 3.17 Sections of Test Wells
- C 4.1 - 4.17 Records of Test Wells
- C 5.0 - 5.26 Geophysical Logs of Test Wells and other selected wells

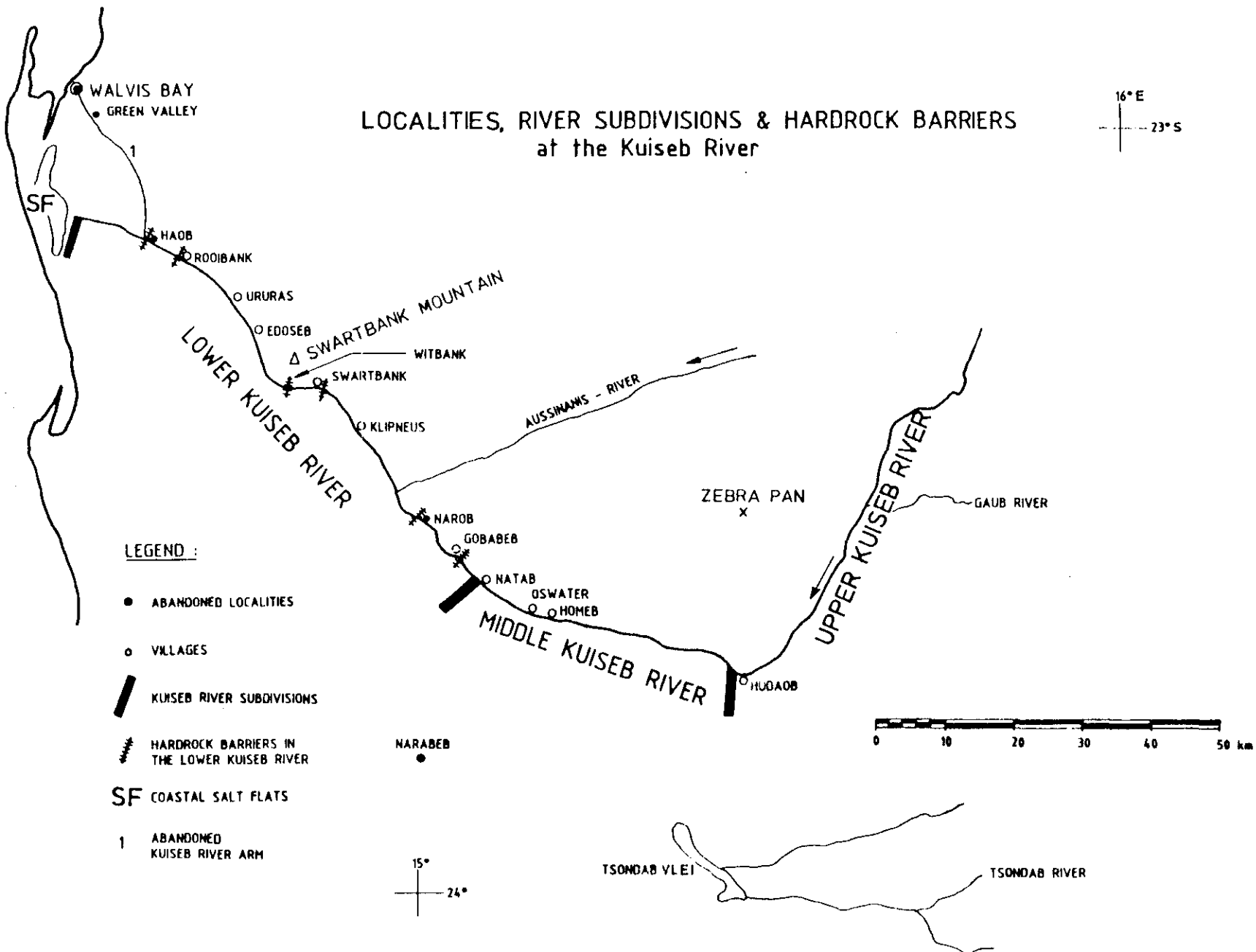


Table 1.3

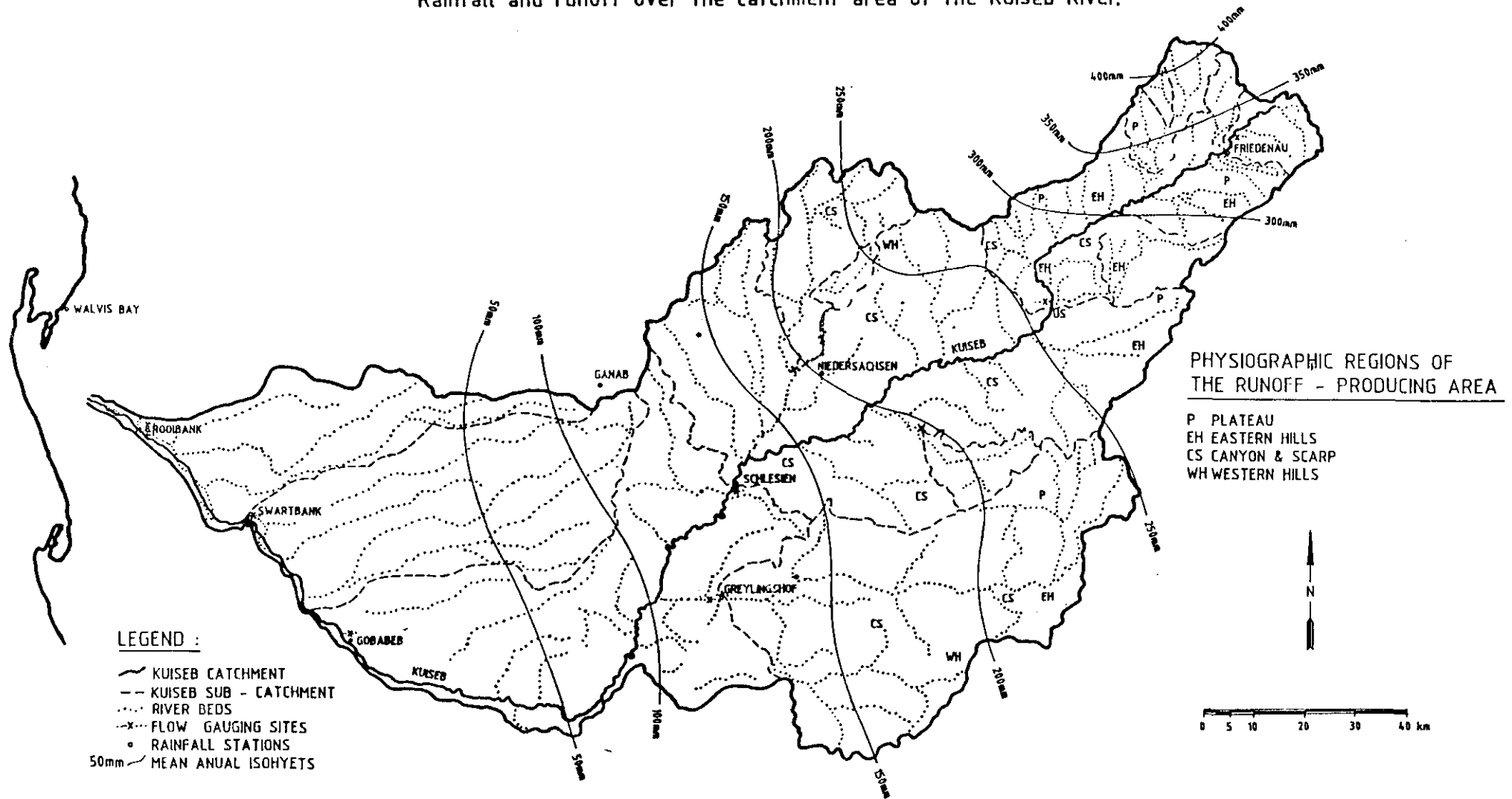
<u>FORMER INVESTIGATION ACTIVITIES FOR GROUNDWATER</u> <u>IN THE KUISEB RIVER VALLEY AND ADJACENT DUNE AREA</u>	
<u>Year</u>	<u>Activities</u>
1952	Geohydrology around Rooibank, by J.R.VEGTER
1959- 1964	Test Drilling downstream Rooibank (B-Area) by DWA
1962	Magnetic Survey by VAN ZIJL & HART (CSIR) in the Kuiseb Dune Area (fig. 1.4)
1965- 1966	Seismic Survey and Test Drilling by VAN ZIJL & HUYSSSEN (CSIR) in the Kuiseb Dune Area and near Sandwich Harbour
1970	Seismic and Gravity Survey by VAN ZIJL & MEYER (CSIR) in the Swartbank Area.
1974	Test wells drilled in the Swartbank Area of the Kuiseb riverbed by DWA
1976	Resistivity Survey by CSIR in the Kuiseb Dune Area, south of Swartbank
1975- 1977	Groundwater Age determination through Isotope Analysis by VOGEL et al. (CSIR-NPRL)
1977	Well point installation in the Delta area
1989- 1991	TDEM & Gravity Survey, Test Drilling & Production Well Installation in the Delta Area, by CSIR & GEODASS LTD.

-----  
 Another prospective area is situated south of the Kuiseb River, the *Kuiseb Dune Area*. It has been investigated since 1962, and often was referred to as an area with a high groundwater potential.

As result from the above surveys, it was a generally accepted opinion within the DWA, that there occurs a groundwater flow from the Kuiseb River towards the sea. Broad basement depressions filled with Tsondab sandstone were supposed to act as principal waterways. A limited number of freshwater outlets at the coast, for instance at Sandwich Harbour seemed to prove this theory. But the exploration results never gave a conclusive picture. The area is covered by moving sand dunes which not only hamper the access, but also conceal the underlying rocks in a manner, that the available exploration methods resulted only in a very limited spatial knowledge.



Rainfall and runoff over the catchment area of the Kuseb River.



SOURCE : HUNTLEY, B.J. ET AL, 1985

After BLOM (1978) this caused a reduction of the average flow of the Kuiseb River by 21%, also delaying the flooding of the lower Kuiseb.

### 3.2.2 Tsondab River

On the southeastern border of the project area, the Tsondab Vlei marks the end of the Tsondab River. This river with a straight length of about 135 km and a catchment area of about 4000 km<sup>2</sup> is much smaller than the Kuiseb (fig 3.2). The Tsondab arises in the plains east of the Naukluft Mountains, at about 1500 m amsl. In westerly direction, this river incised its course canyonlike at the escarpment and enters after a 60 km run near Abbabis at 1075 m amsl the Namib Desert. From here on, the Tsondab River moves through the desert plains 75 km westward to the Tsondab Vlei. Here its ephemeral surface flow ends in a flat pan of less than 50 km<sup>2</sup> size, at 650 m amsl, about 90 km east of the Atlantic Ocean.

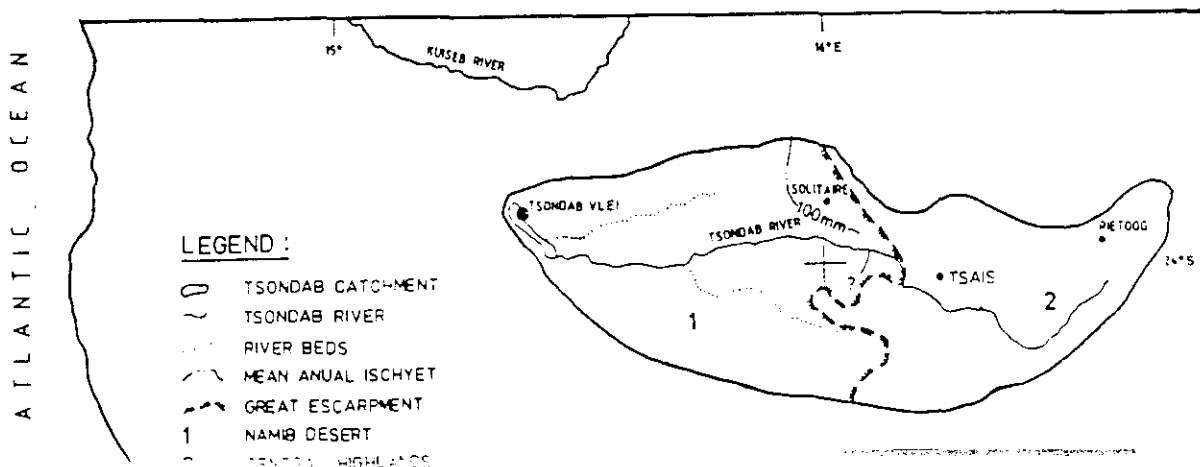
From time to time ephemeral floods fill the vlei, where they evaporate and partly infiltrate into the ground.

The actual runoff does not permit the river to penetrate into the sand dunes further west of the Tsondab Vlei, but this could have happened in Plio-Pleistocene times (LANCASTER 1984).

From the Tsondab River, no measured records about its runoff are available.

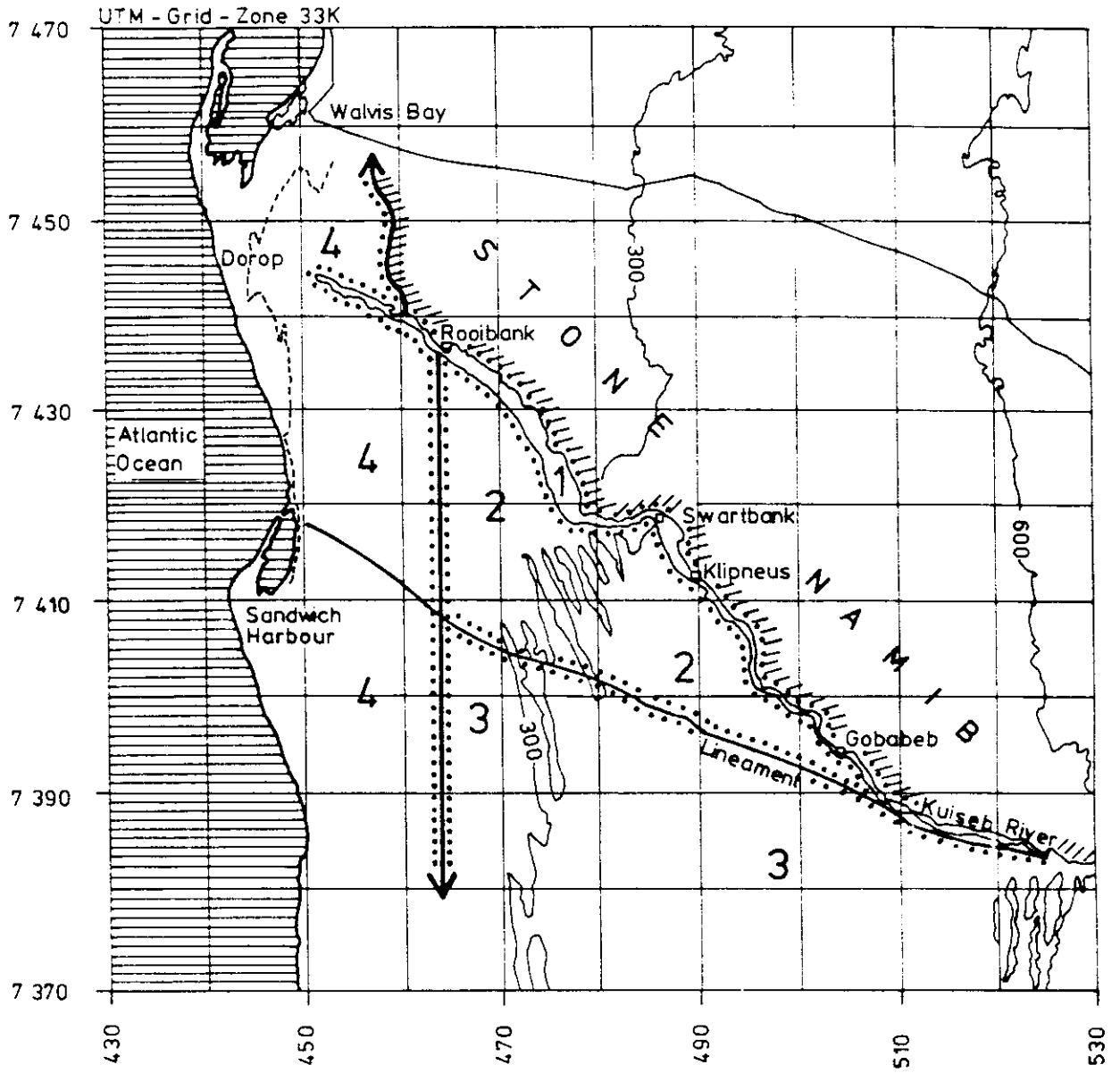
About the rainfall in the Tsondab catchment area, measurements at Solitaire, 60 km east of the Tsondab Vlei but yet within the eastern margin of the Namib Desert, and some 10 km west of the escarpment are available. They showed between 1968 and 1986 an average annual rainfall of 130 mm, with a maximum of 266 mm/a and a minimum rainfall of 44.8 mm/a.

CATCHMENT AREA OF THE TSONDAB RIVER



# KUISEB DUNE AREA

## Geological and Geohydrological Subareas



**LEGEND :**

- 1 - ACTIVE KUISEB SUBAREA
- 2 - KUISEB SOUTH SUBAREA
- 3 - TSONDAB SUBAREA
- 4 - COAST SUBAREA



BOUNDARY BETWEEN SAND NAMIB AND STONE NAMIB



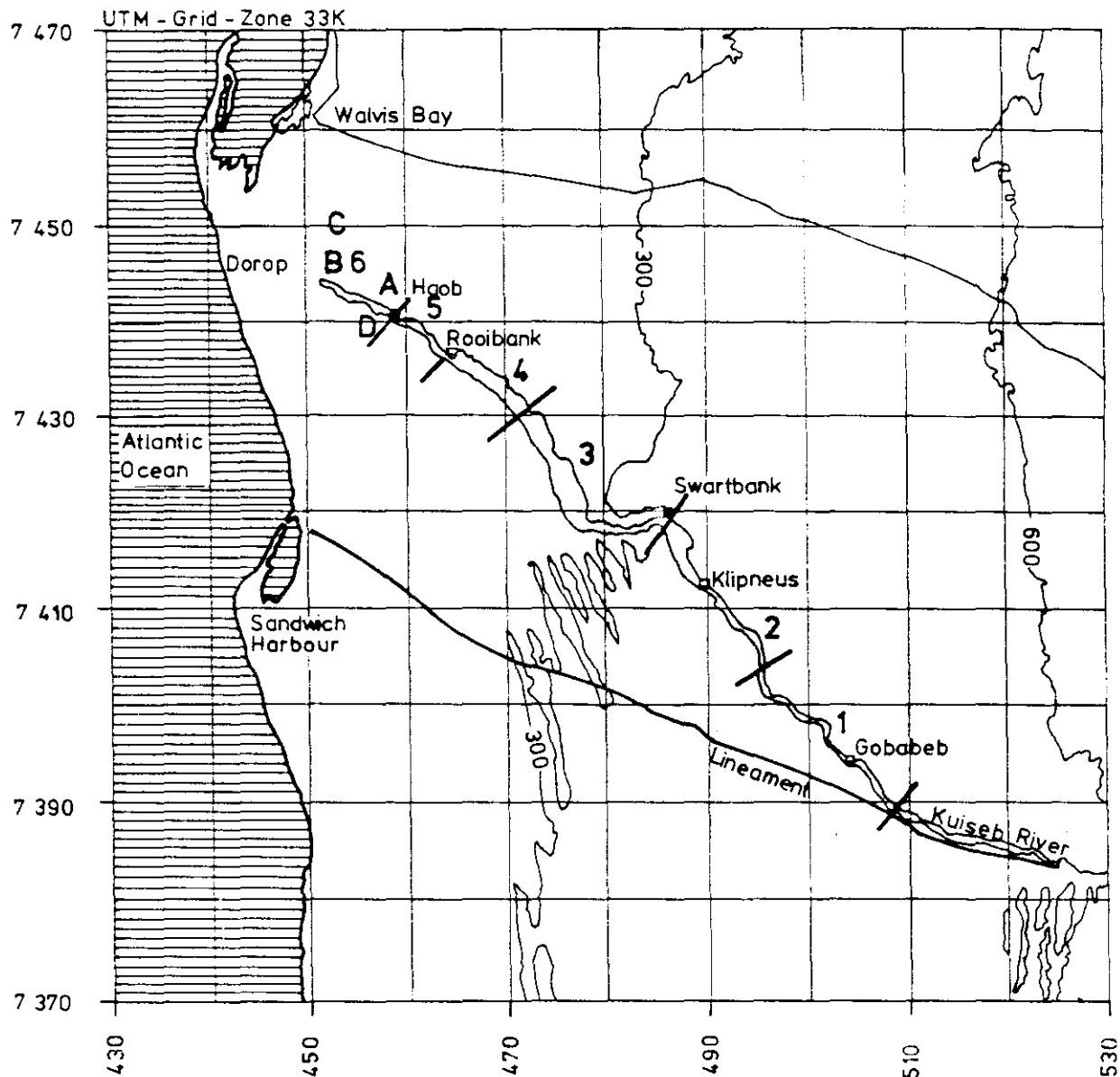
COASTAL SALTWATER BOUNDARY

 300m CONTOUR LINE in m a.m.s.l.

FIGURE 4.5

# KUISEB DUNE AREA

## Groundwater compartments of the Active Kuiseb River Plain



The 6 groundwater compartments of the Active Kuiseb River Plain

- 1. NATAB - AUSSINANIS
- 2. KLIPNEUS
- 3. SWARTBANK

- 4. ROOIBANK A
- 5. HAOB
- 6. B - AREA, COMPOSED OF

- 6A B - ABSTRACTION AR
- 6B DOROP SOUTH AREA
- 6C DOROP NORTH AREA
- 6D KUISEB CHANNEL ARE

ACTIVE KUISEB SUBAREA

ROOIBANK - A

Drawdown of the groundwater table in observation wells in relation to annual production, between 1985 and 1994

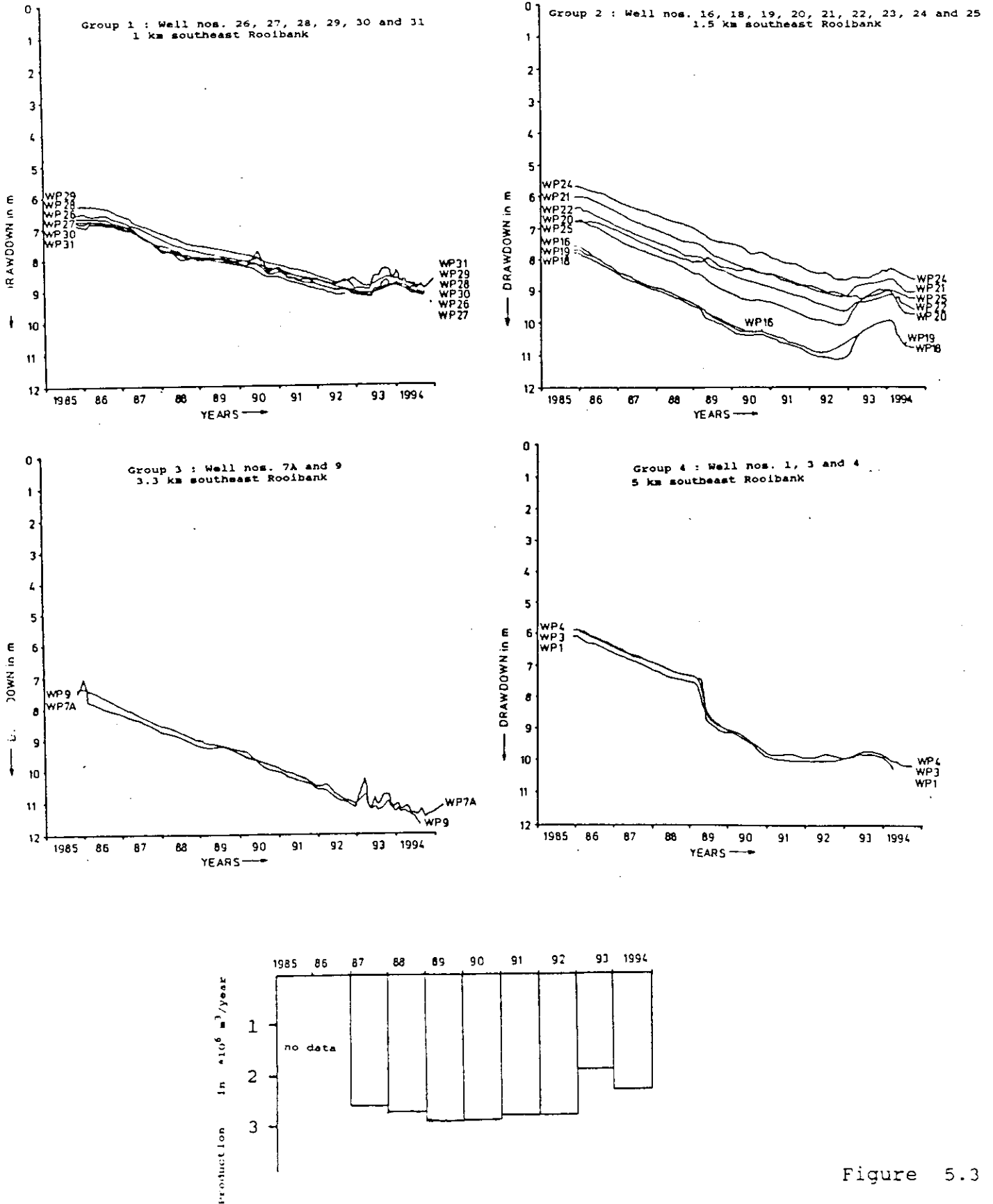


Figure 5.3

The Dorop North Subarea constitutes the continuation of Dorop South, in northerly direction. The difficult access is hampering the development of this area, as well as poorer water quality and the obvious difficulty to control saline intrusion.

The Kuiseb Channel Subarea is situated south of the Kuiseb River, between Rooibank and the B - Abstraction Area. It forms part of the Kuiseb palaeochannel system, belonging to PCH # 6.

The areal extension of this channel is limited to some 15 km<sup>2</sup>, with an aquifer thickness below 10 m. Groundwater recharge is unknown, groundwater seepage from the Rooibank A aquifers could not be proved by EM interpretation.

#### 5.2.2 Kuiseb South Subarea

The results of the airborne geophysical investigations in this area made the original concept of dewatering the groundwater reserves stored in the Tsondab Sandstone look even more promising. It was thought that the palaeochannels detected by this geophysical survey could have a higher permeability than the Tsondab and could therefore be used as drainage lines while mining the Tsondab water. Therefore Kuiseb South was selected as the principal target area for groundwater exploration and has been investigated in detail.

Figures 5.4 + 5.5, taken of the 1990 DWA report no. 12/7/1/6/2, (W.SEIMONS) show a summary of more than 30 years of investigations in this area, the results of geophysical ground surveys (mainly seismics and magnetics), test drillings, hydrochemical and isotope analyses.

Between the Kuiseb River and the coast, this model shows under moving sand dunes a nearly complete coverage with Tsondab sandstone. This sandstone rests on crystalline basement and fills east west directed broad valleys. There is one aquifer only, the Tsondab Sandstone, which receives its recharge through direct contact from the Kuiseb River alluvium and in a hydraulic continuity discharges the groundwater at the coast. To tap this uniform aquifer with  $1.5 \times 10^2$  m<sup>3</sup> stored groundwater ( van Zijl & Huyssen 1967) has been tried since then, but the big Tsondab channel has not been found yet. A 50 m thick aquifer has been proved, but the transmissivities and with it the yields remained low ( around 5 m<sup>3</sup>/h ).



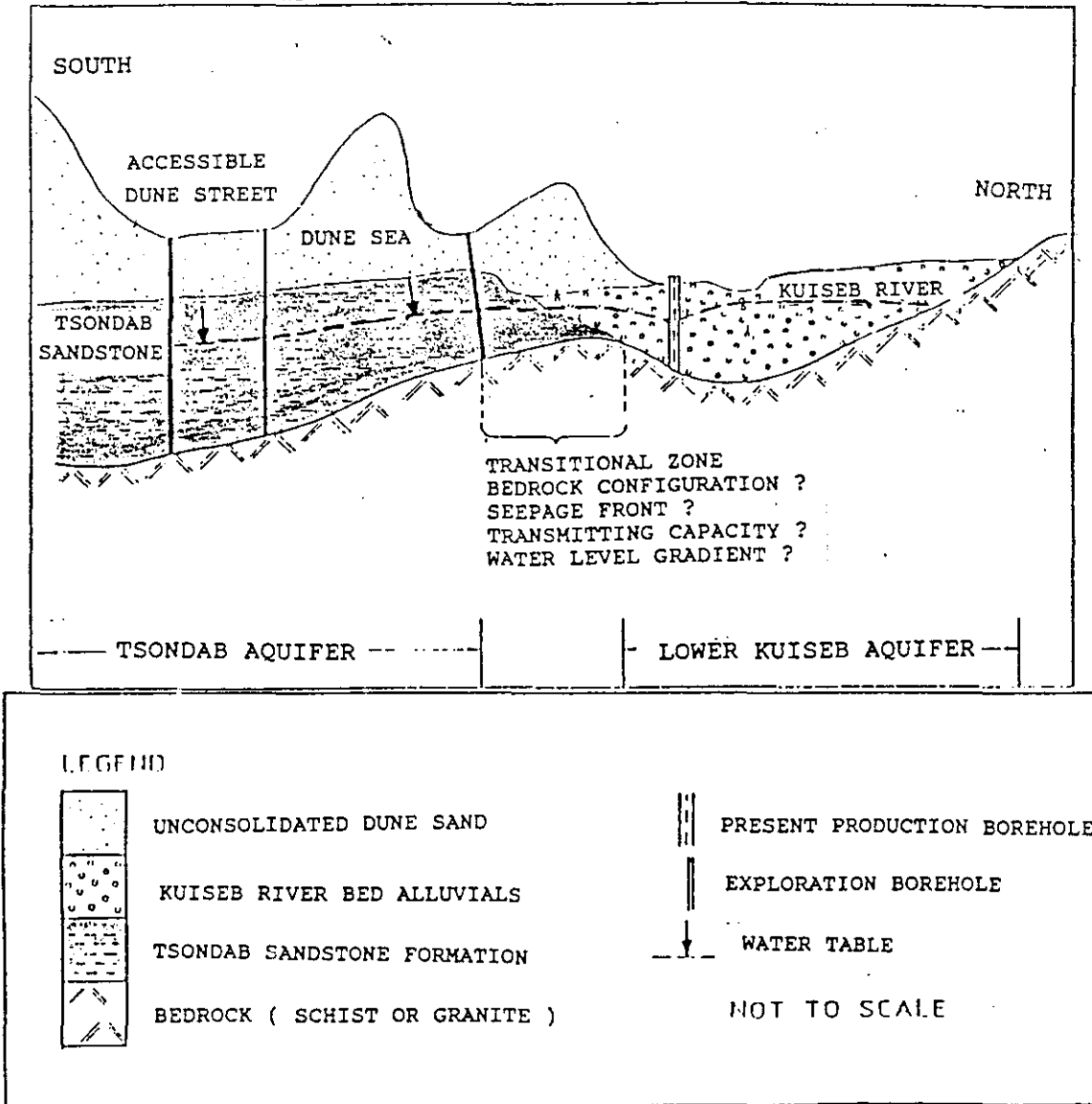
The EM - survey done in 1992 showed, and this has been proved through the ground surveys since, that the geohydrologic situation in the referred area is very complex (annex A 2). On a rough comparison, the basement low of fig 5.5, denominated areas 1 and 2, coincide with PCH's # 2, # 3 and # 4. But the uniform aquifer model of figs 5.4 and 5.5 had to be substituted by a model with different aquifers separated repeatedly by hydraulic boundaries. And the groundwater from the active Kuiseb riverplain cannot recharge directly into the Tsondab Sandstone, because this formation is not bordering the Kuiseb River.

The Kuiseb South Subarea comprises a triangle. The northeastern boundary against the active Kuiseb is actually to nearly 70 % composed of a no flow boundary (48 km), and to 30 % (24 km) of a boundary which allows groundwater inflow into the palaeochannels. Only through these channel inlets, recharge into the subarea is considered to take place. Some 30 years ago, due to the then higher groundwater level in the active Kuiseb River aquifers, the inlet areas were around 5 km larger than today.

High lying basement at the southern flank of the lineament structure forms a no flow boundary against the Tsondab Subarea - refer to figs 5.7 - 5.10.

To the coastal area in the west, groundwater flow is supposed to continue within the palaeochannels. The gradient of the groundwater table is directed to a westerly direction.

Former model of groundwater flow  
between Active Kuiseb and Kuiseb South subareas  
(vertical section)

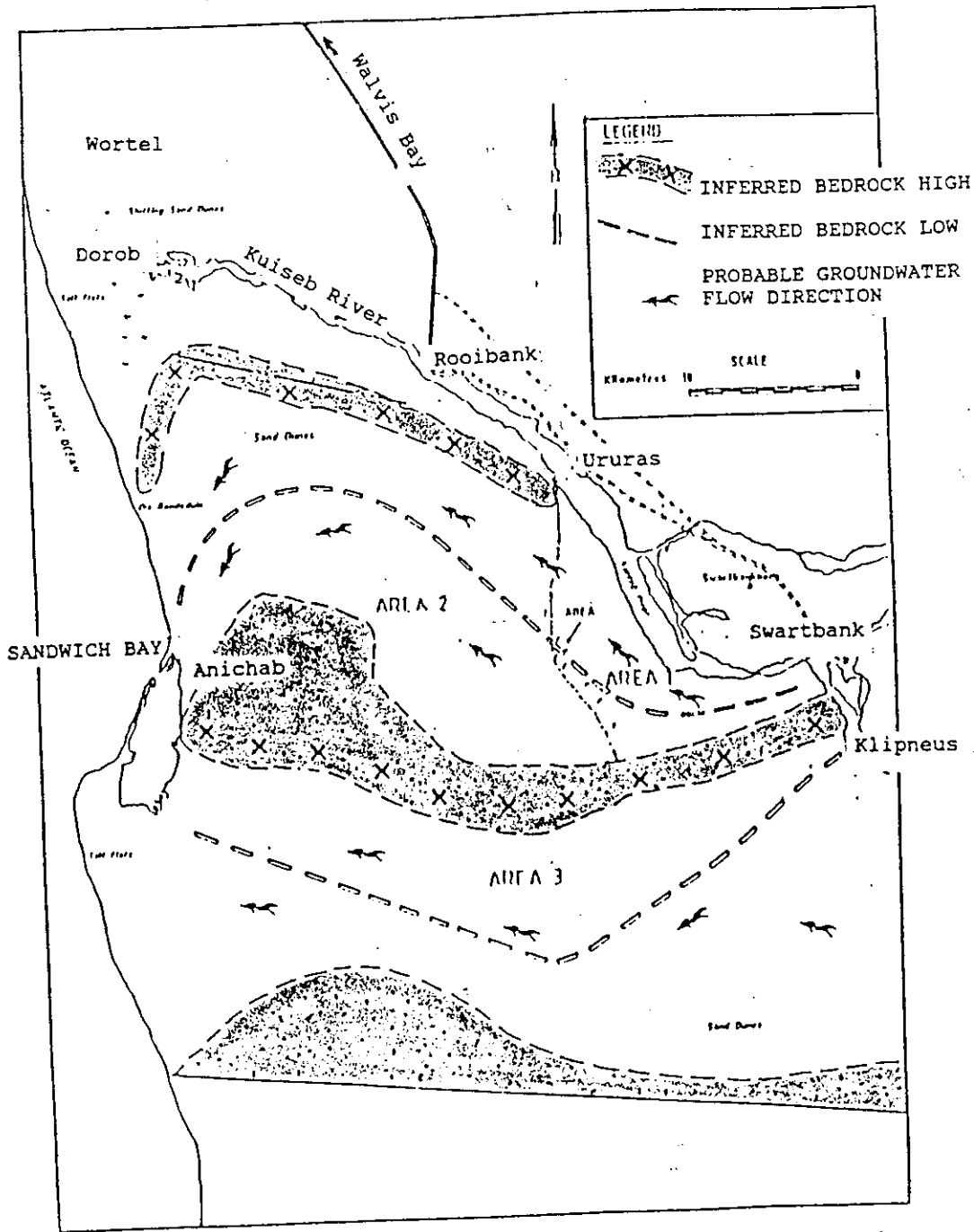


DIAGRAMMATICAL SKETCH TO INDICATE POSSIBLE RELATIONSHIP  
BETWEEN LOWER KUISEB AQUIFER AND TSONDAB AQUIFER

Source: DWA report 12/7/1/6/2

Figure 5.4

Former model of groundwater flow  
in palaeochannels in the Kuiseb South Subarea  
(regional map)



LOCALITY MAP OF LOWER KUISEB RIVER WITH INFERRED PALEO-CHANNELS  
BELOW PRESENT DUNE SEA (AFTER VAN ZIJL AND HUYSSSEN, 1967)

Source: DWA report 12/7/1/6/2

Figure 5.5

compartments in this subarea :

Table 6.1

Total Dissolved Solids in the Active Kuiseb Subarea  
all values in mg / l

COMPARTMENTS	AVERAGE	MINIMUM	MAXIMUM
Klipneus	1,440	330	4,760
Swartbank	600	170	1,665
Rooibank A	950	420	3,590
B - Abstraction*	800	650	1,050
Dorop South*	1,100	900	1,300
Dorop North*		1,300	2,100

\*) from BUSH 1991

The considerable variations in the groundwater quality within the individual compartments of the Active Kuiseb Subarea let suppose, that they do not constitute homogeneous aquifers. On the contrary, it is a question of separate groundwater compounds with differentiated groundwater bodies.

The general groundwater flow downstream seems also reduced. Only between Swartbank and Rooibank aquifers, a general increase in overall salinity in downstream direction has been confirmed.

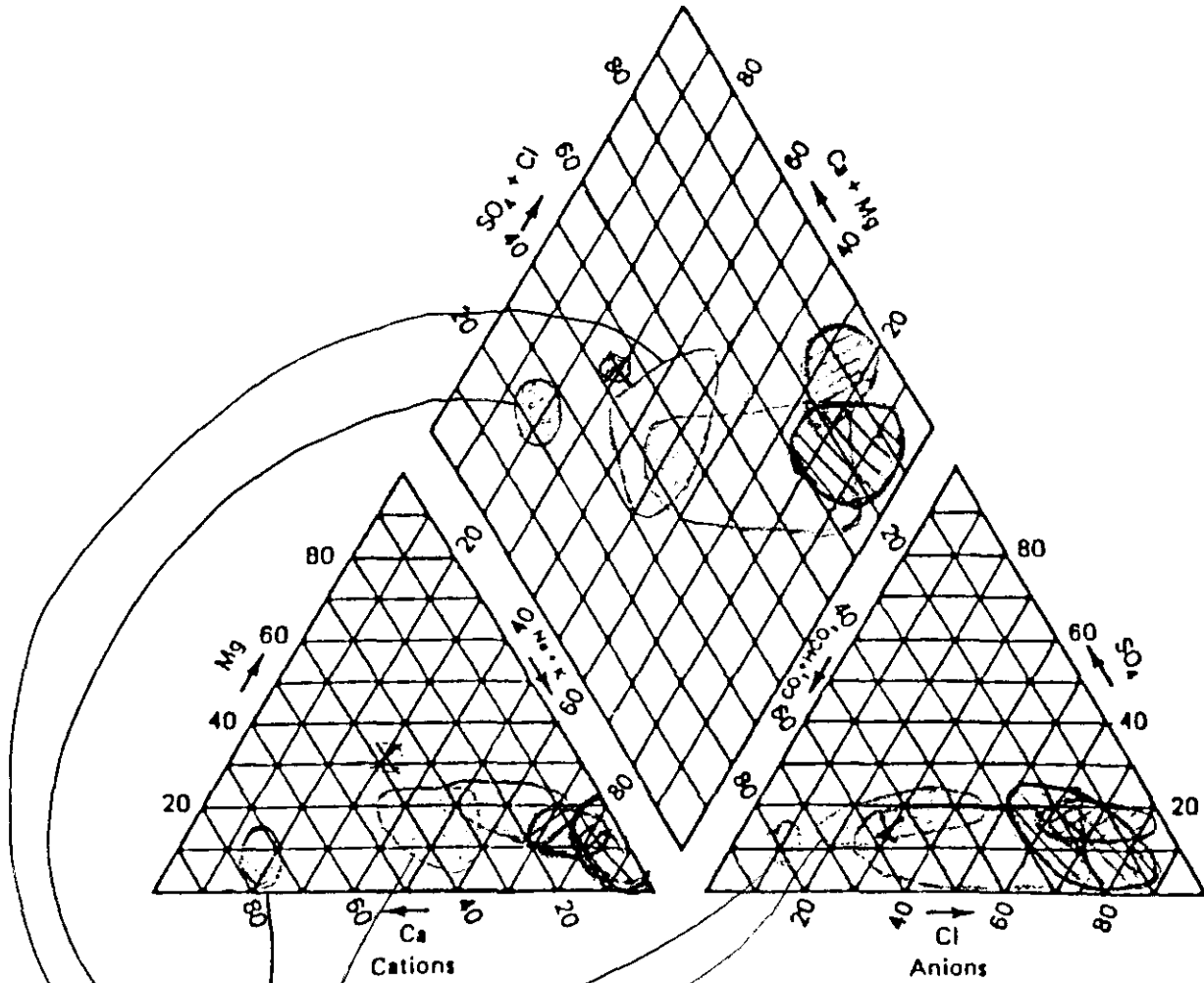
The following Piper Diagram (fig 6.1) shows the meq % distribution of the cation and anion groups of flood waters against the groundwater in the individual aquifers.

Two analysis of typical Kuiseb River flood waters show the predominance of the  $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$ - $\text{HCO}_3^-$  ions. These are waters originating in the upper Kuiseb subcatchment area in the Highlands (fig 3.1). They are not contaminated by floods of the tributaries proceeding from the Stone Namib.

On the same graph, the results of 17 production BH's in the Swartbank compartment show the ion exchange occurred in the groundwater since infiltration took place. The  $\text{Na}^+$  and  $\text{K}^+$  as well as the  $\text{Cl}^-$  portion increased considerably their participation. For interpretation, see also 6.2.2.

KUISEB DUNE AREA

Hydrochemical cluster of main cation and anion groups, in meq %



Kuiseb flood water

Active Kuiseb Subarea -  
Swartbank production wells



Kuiseb South Subarea -  
PCH # 1, # 2, TS # 2



PCH # 3, # 4.



PCH # 3 = well 70, highest yield in this subarea



PCH # 5, south of Roebank

### 6.2.2 Kuiseb South Subarea

Table 6.2 shows the mean salinity as well as the minimum and maximum values in the individual aquifers of this subarea. The PCH's are characterized through different mean values of overall salinity. On the other hand, the limited number of analyses and their unequal spatial distribution recommends some caution in comparing the overall values, for instance in PCH # 1.

Table 6.2

#### KUISEB SOUTH SUBAREA

#### Salinity in the individual aquifers

AQUIFER	No*	TDS - values in mg / l		
		mean	minimum	maximum
PCH # 1	2	<b>3,050</b>	3,000	3,100
PCH # 2	5	<b>660</b>	250	1,075
PCH # 3	13	<b>1,000</b>	320	3,200
PCH # 4	11	<b>750</b>	290	2,250
PCH # 5	23	<b>1,200</b>	320	3,270
TS # 2/5	6	<b>1,060</b>	380	1,760

\* ) No of analyses

The southernmost PCH # 1 contains a brackish groundwater, clearly separated from the northern PCH #2 through its overall salinity.

PCH's # 2 to # 5 as well as the Tsondab aquifers # 2 to # 5 do not show a clear separation from each other, with mean overall salinities between 660 and 1.200 mg/l.

The lowest average salinity is found in the PCH's #3 and #4, south of Swartbank. Especially in PCH # 3, the analysis at hand show a diminishing mineralization downstream. This let suppose a groundwater flow not only within this PCH, but a recharge also from PCH # 4 southwestwards into PCH # 3.

In PCH # 5, the high salinities are concentrated south of Rooibank, in the southwest running ( downstream ) part of the channel. Upstream, this PCH shows as well as PCH # 4, low salinities

especially near the boundary to the Active Kuiseb Subarea . But on the other hand, some wells even in this border area prove with their high mineralization the existence of separated aquifer bodies within the same PCH.

Tables 6.3 and 6.4 show the distribution of the main anion and cation groups, in mean values and in minimum and maximum values.

Table 6.3 KUISEB SOUTH SUBAREA

Mean values of cation and anion groups in meq%,  
in the individual aquifers

AQUIFER	No*	Na <sup>+</sup> /K <sup>+</sup>	Ca <sup>2+</sup> /Mg <sup>2+</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup> /SO <sub>4</sub> <sup>2-</sup>
PCH # 1	2	78	22	10	79
PCH # 2	2	70	30	27	72
PCH # 3	12	63	37	40	57
PCH # 4	4	68	32	31	67
PCH # 5	13	85	15	25	74
TS # 2-5	4	78	22	15	83

\*) No of analyses

Table 6.4 KUISEB SOUTH SUBAREA

Minimum and maximum values of cation and anion groups in meq %  
in the individual aquifers

AQUIFER	No*	Na-K		Ca-Mg		HCO <sub>3</sub>		Cl-SO <sub>4</sub>	
		1	2	1	2	1	2	1	2
PCH # 1	2	77	80	20	23	4	16	63	94
PCH # 2	2	70	71	29	30	16	37	63	81
PCH # 3	12	32	92	8	68	2	58	38	98
PCH # 4	4	34	80	20	66	11	69	30	89
PCH # 5	13	76	93	7	24	7	69	31	92
TS # 1-5	4	70	95	5	30	6	25	74	92

\*) No of analyses

1 = minimum, 2 = maximum value

Figure 6.1 shows in a Piper diagram the continued ion exchange process, the surface water is suffering during infiltration and following aquifer flow. This is proven through the increasing  $\text{Na}^+\text{-K}^+$  and  $\text{Cl}^-$  portion on the expense of the  $\text{Ca}^{2+}\text{-Mg}^{2+}$  and  $\text{HCO}_3^-$  portion.

The downstream portion of PCH # 5 is characterized through a very far reaching exchange with a participation of waters with a 90 %  $\text{Na}^+\text{-K}^+$  and  $\text{Cl}^-$  content, on a meq base.

On the Piper diagram, special attention is given to BH 70 (PCH # 3 of the Kuiseb South Subarea). This well has a markedly lower  $\text{Na}^+\text{-K}^+$  meq%-share than all other wells in this subarea, even lower than the production wells within the Swartbank compartment of the Active Kuiseb Subarea. This fact gains importance when considered that BH 70 proved to be the well with the most favourable hydraulic properties so far tested in the Kuiseb South Subarea.

### 6.2.3 Quality variation in time

The groundwater in the Active Kuiseb aquifers showed over the last 20 / 30 years often accentuated variations in their overall salinity, which on average demonstrate a slight increase. A detailed look indicates that this is not a general and only one way phenomena, but often an up and down in dependance of the limited natural recharge events and of the artificial discharge conditions (abstraction).

Figs. 6.2 - 6.5 show quality variations in the individual groundwater compartments of the Active Kuiseb Subarea, namely Klipneus, Swartbank, Rooibank-A and B.

In the Klipneus compartment, over a period of 7 years (1977 - 1984), on average overall salinity in 6 observation wells has remained stable.

In the Swartbank compartment, 10 production wells show over a 22 years period (1971 - 1993) on average a slight increase in their mineralization.

In the Rooibank A compartment, data at hand from 4 observation wells are not conclusive about a general trend over the last 21 years, due to their varying behaviour.