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

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Groundwater Exploration in the Kuiseb Dune Area

Part 1 - Text

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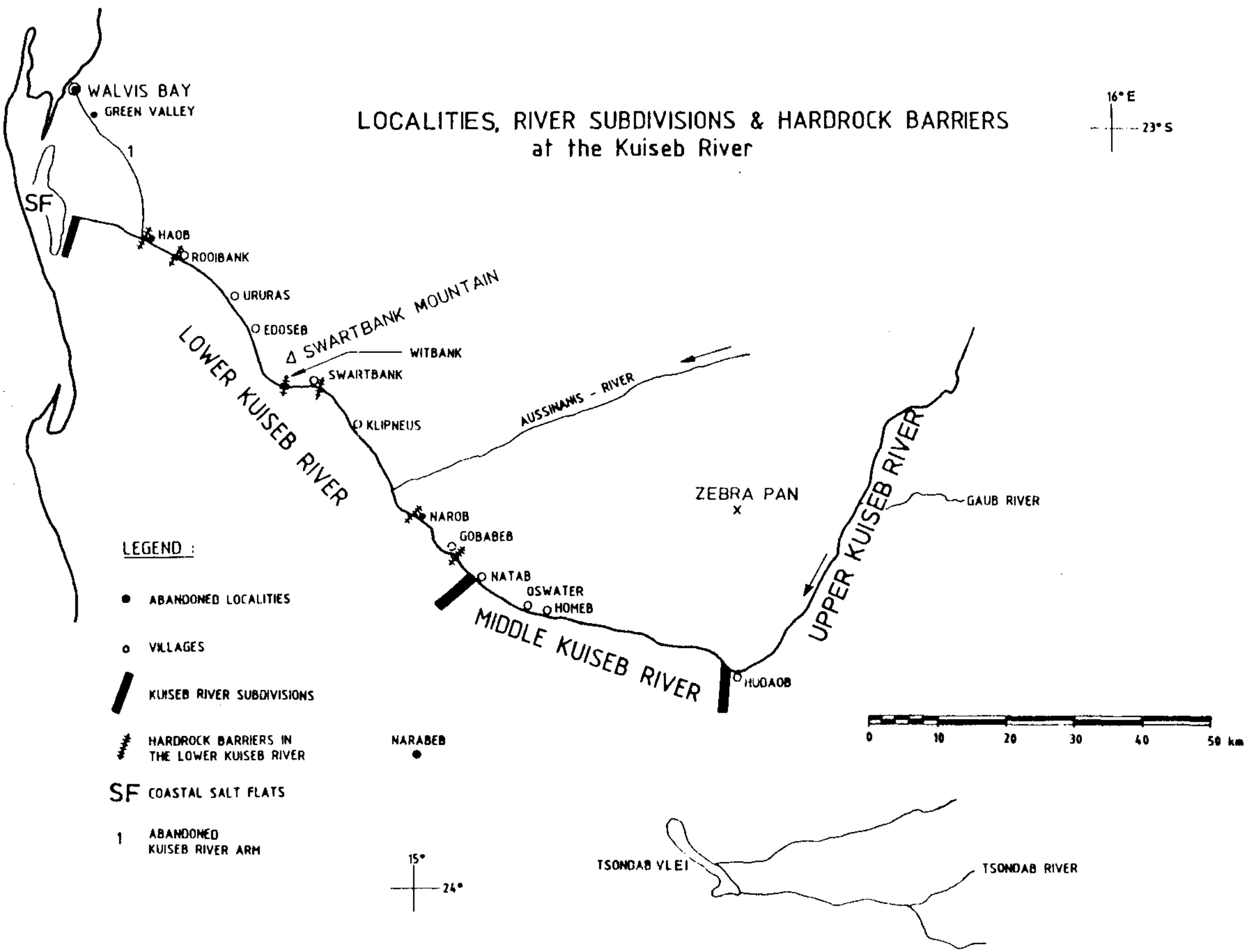
Table 1.3

FORMER INVESTIGATION ACTIVITIES FOR GROUNDWATER IN THE KUISEB RIVER VALLEY AND ADJACENT DUNE AREA

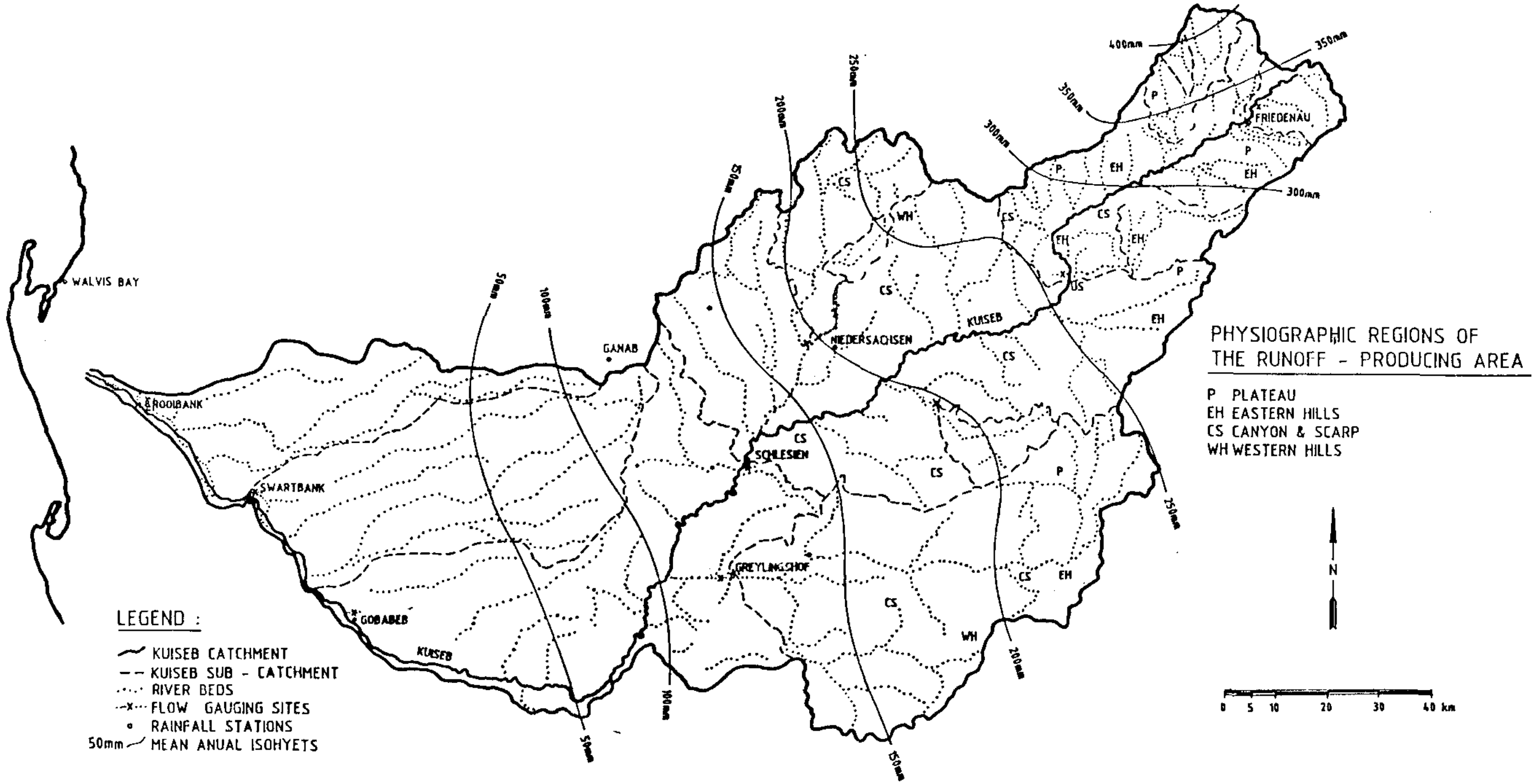
Year	Activities
1952	Geohydrology around Rooibank, by J.R.VEGTER
1959-1964	Test Drilling downstream Rooibank (B-Area) by DWA
1962	Magnetic Survey by VAN ZIJL & HART (CSIR) in the Kuiseb Dune Area (fig. 1.4)
1965-1966	Seismic Survey and Test Drilling by VAN ZIJL & HUYSSEN (CSIR) in the Kuiseb Dune Area 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.


LOCALITIES, RIVER SUBDIVISIONS & HARDROCK BARRIERS
at the Kuiseb River
16° E
23° S
WALVIS BAY
GREEN VALLEY
1
SF
HAOB
ROOIBANK
URURAS
EDOSEB
SWARTBANK MOUNTAIN
WITBANK
SWARTBANK
KLIPNEUS
AUSSINANIS - RIVER
LOWER KUISEB RIVER
NAROB
GOBABEB
NATAB
OSWATER
HOMEB
MIDDLE KUISEB RIVER
HUDAOB
UPPER KUISEB RIVER
GAUB RIVER
ZEBRA PAN
LEGEND :
ABANDONED LOCALITIES
VILLAGES
KUISEB RIVER SUBDIVISIONS
HARDROCK BARRIERS IN THE LOWER KUISEB RIVER
SF COASTAL SALT FLATS
1 ABANDONED KUISEB RIVER ARM
NARABEB
0 10 20 30 40 50 km
15°
24°
TSONDAB VLEI
TSONDAB RIVER

Rainfall and runoff over the catchment area of the Kuiseb 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 km² 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 km² size, at 650 m amsl, about 90 km east of the Atlantic Ocean.

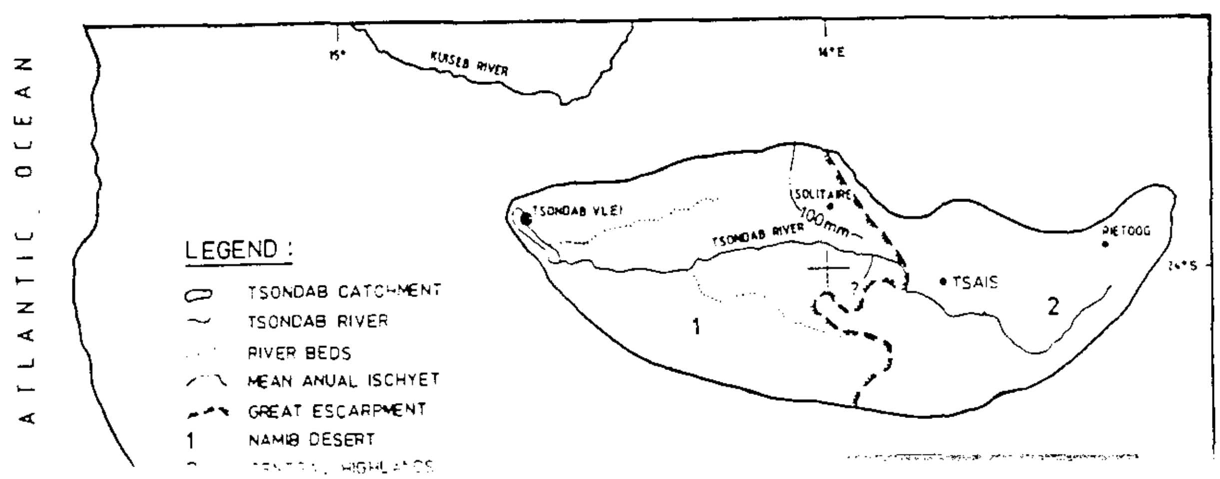
From time to time ephemeral floods fill the vlei, where they evaporate and partly infiltrate into the ground.

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.

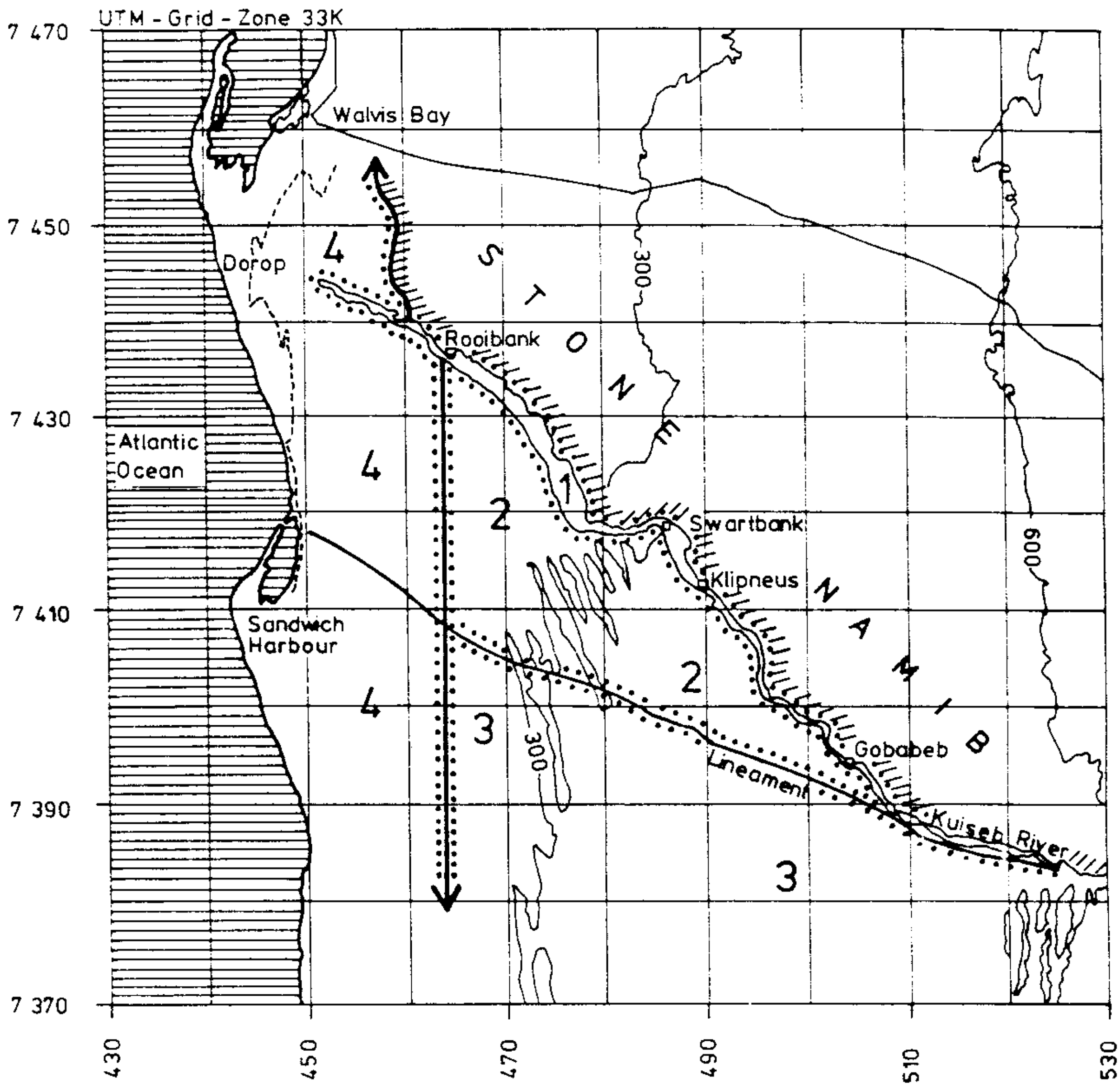
About the rainfall in the Tsondab catchment area, measurements at Solitaire, 60 km east of the Tsondab Vlei but yet within the eastern margin of the Namib Desert, and some 10 km west of the escarpment are available. They showed between 1968 and 1986 an average annual rainfall of 130 mm, with a maximum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

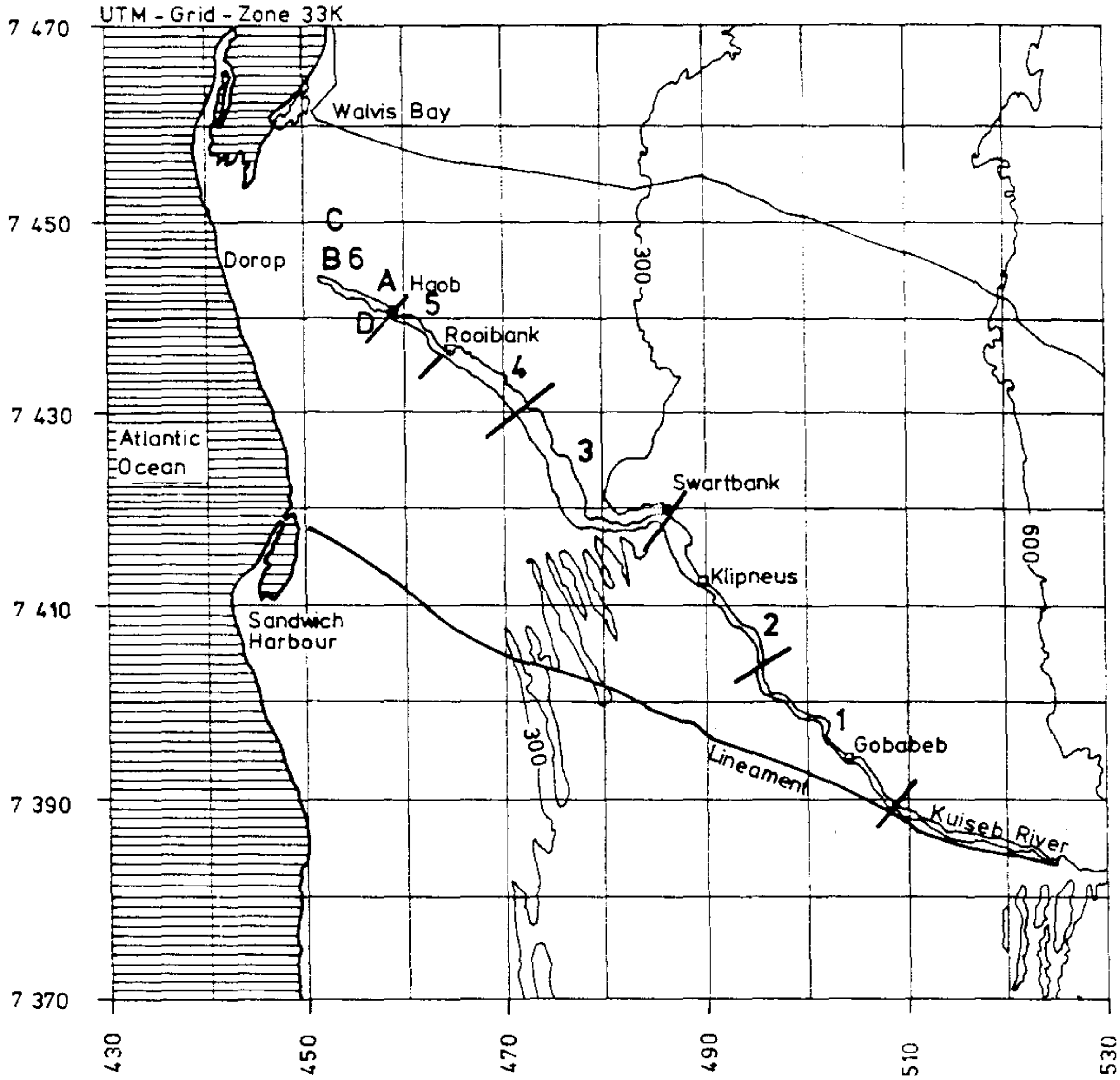
COASTAL SALTWATER BOUNDARY

300 ~ 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

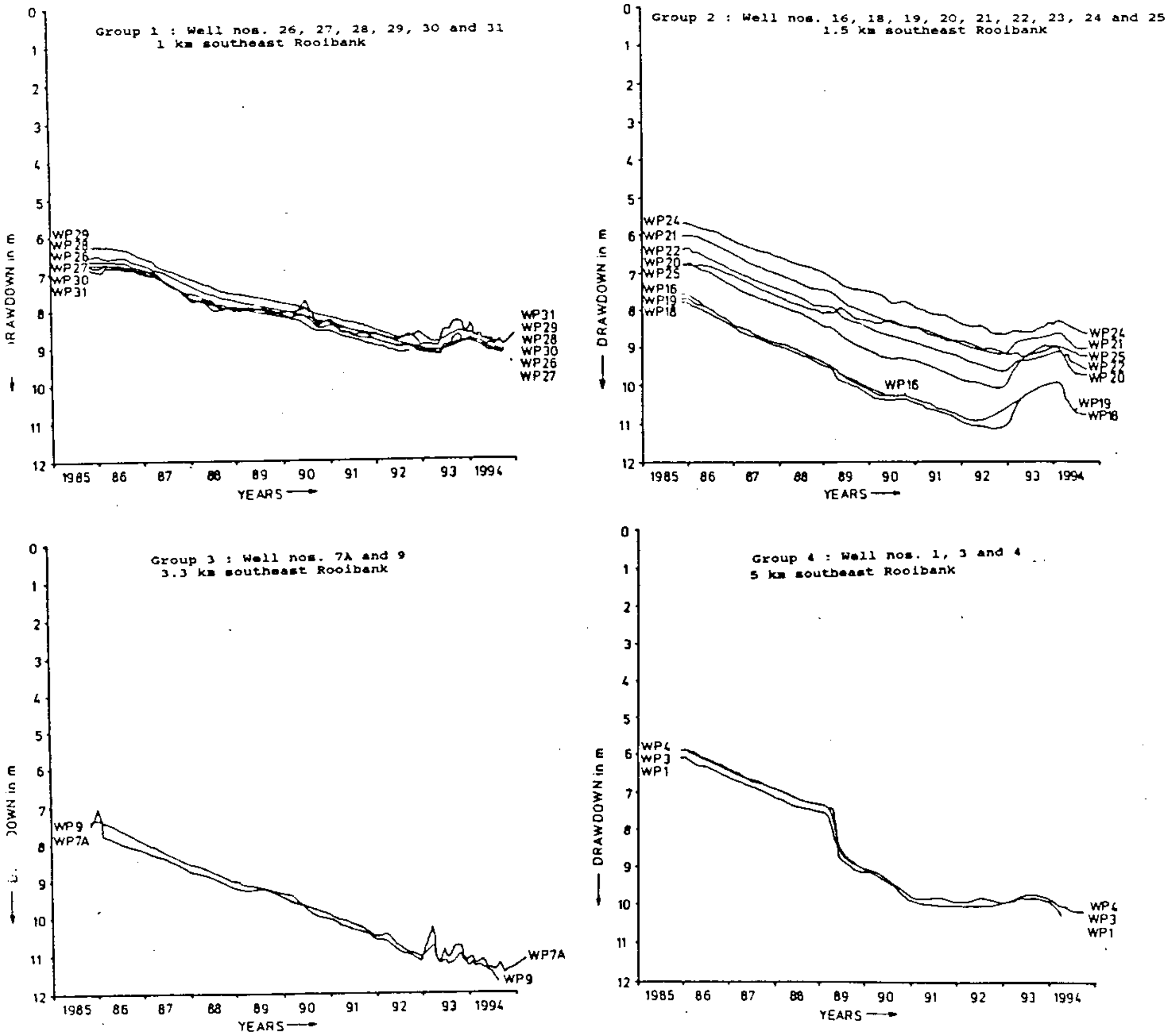
1. NATAB - AUSSINANIS
2. KLIPNEUS
3. SWARTBANK
4. ROOIBANK A
5. HAOB
6. B - AREA, COMPOSED OF
   - 6A B - ABSTRACTION AR
   - 6B DOROP SOUTH AREA
   - 6C DOROP NORTH AREA
   - 6D KUISEB CHANNEL ARE

FIGURE 5.1

ACTIVE KUISEB SUBAREA

ROOIBANK - A

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



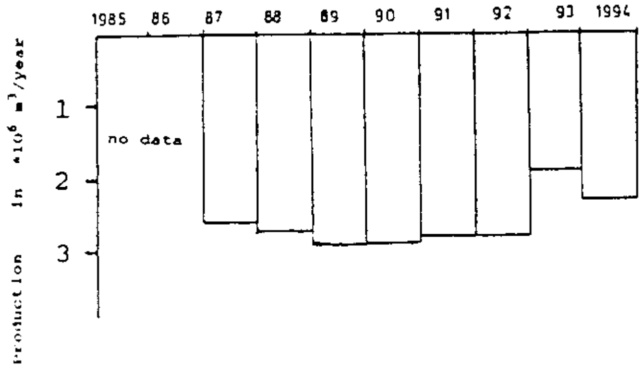


Figure 5.3

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^2, 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 x 10^9 m3 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^3/h).

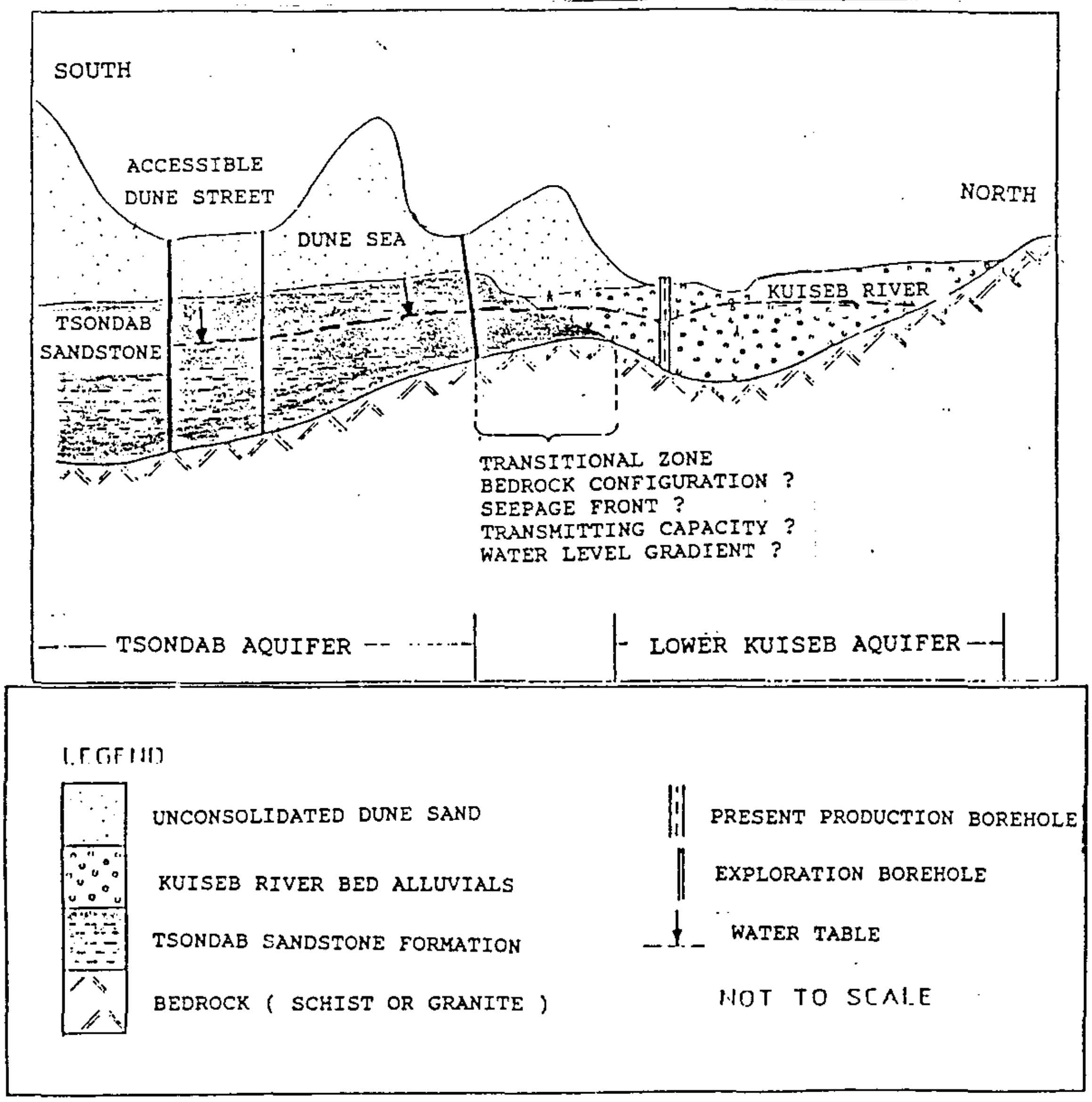
The EM - survey done in 1992 showed, and this has been proved through the ground surveys since, that the geohydrologic situation in the referred area is very complex (annex A 2). On a rough comparison, the basement low of fig 5.5, denominated areas 1 and 2, coincide with PCH's # 2, # 3 and # 4. But the 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)

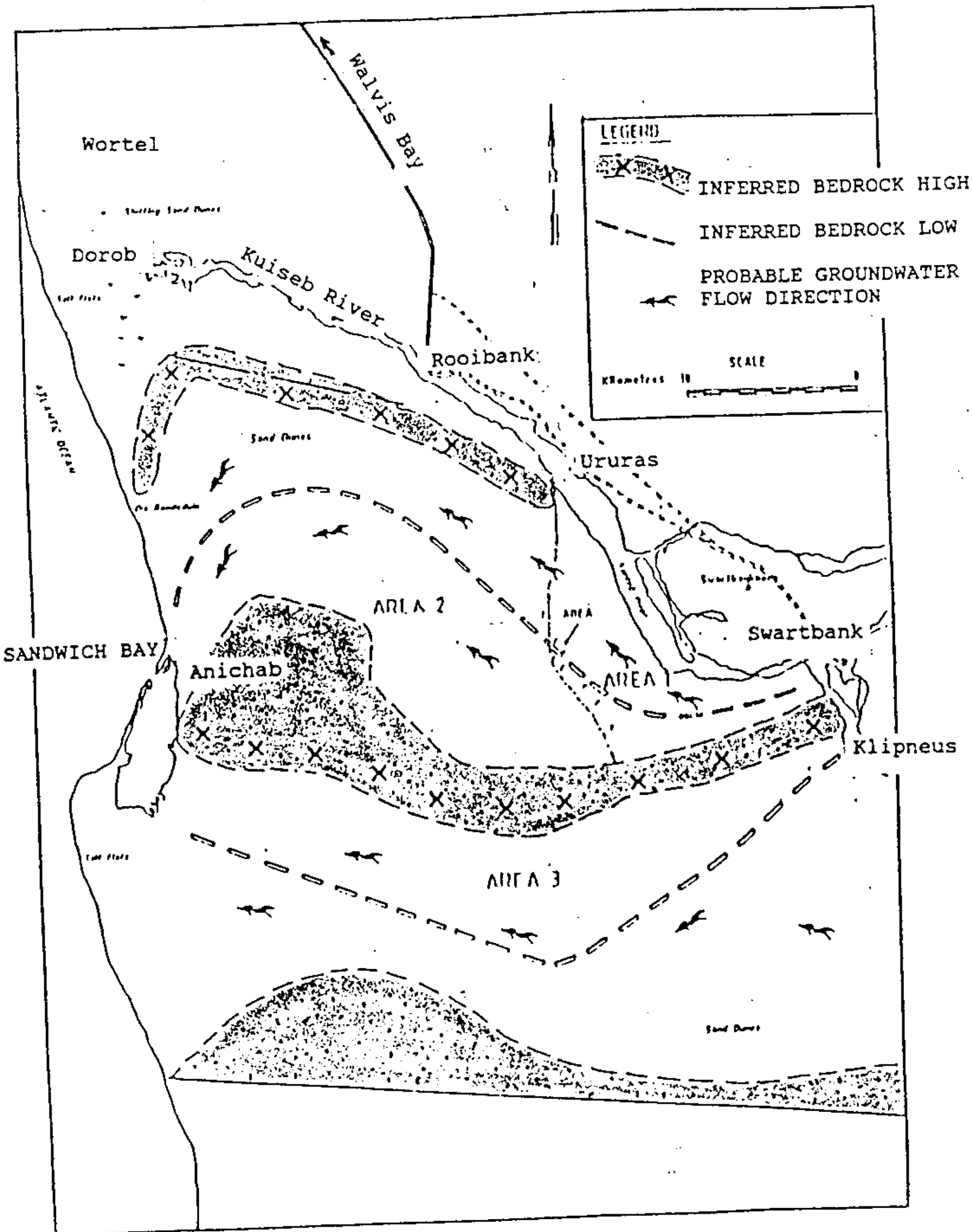


DIAGRAMMATICAL SKETCH TO INDICATE POSSIBLE RELATIONSHIP BETWEEN LOWER KUISEB AQUIFER AND TSONDAB AQUIFER

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 HUYSSEN, 1967)

Figure 5.5

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

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.

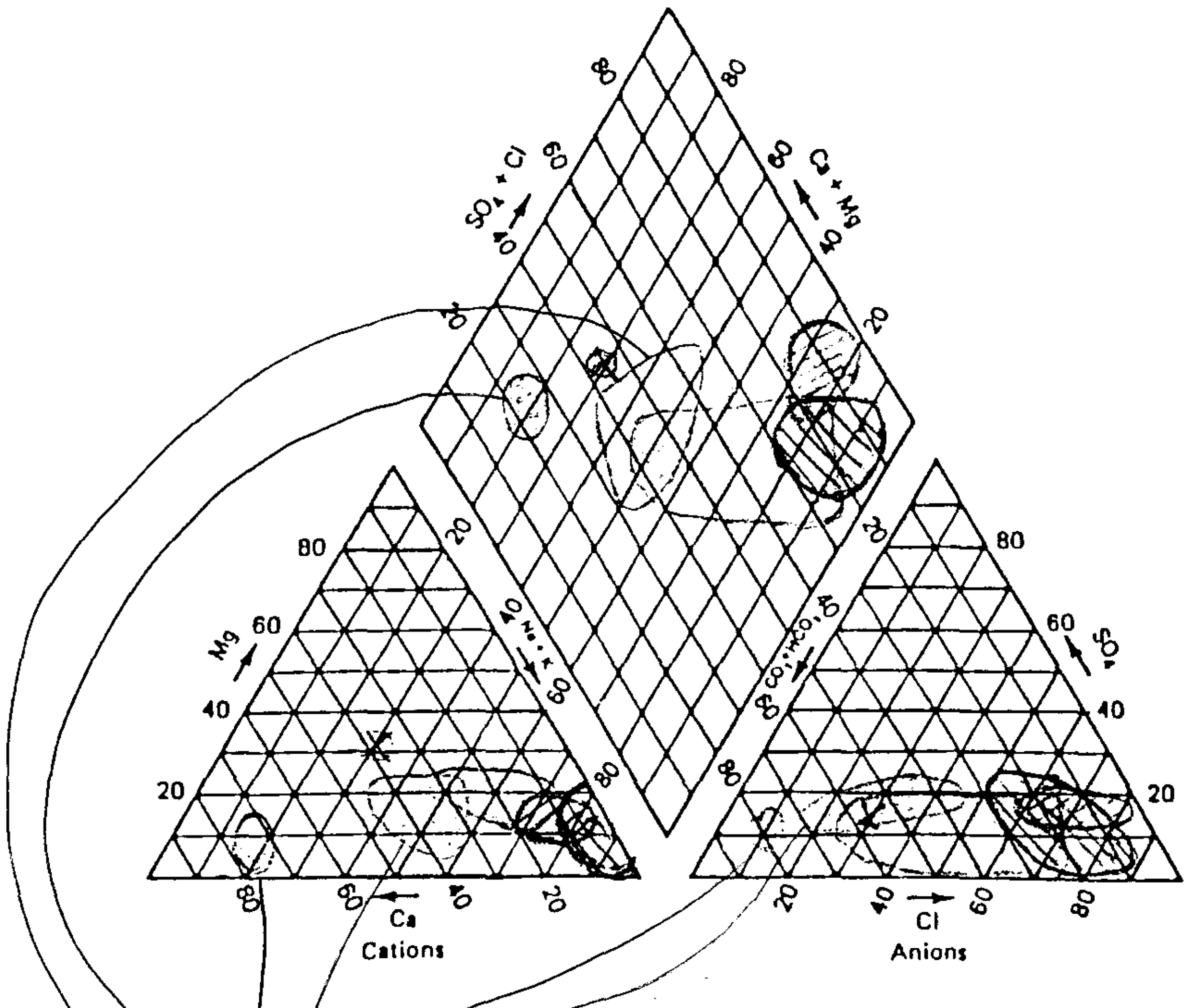
The following Piper Diagram (fig 6.1) shows the meq % distribution of the cation and anion groups of flood waters against the groundwater in the individual aquifers.

Two analysis of typical Kuiseb River flood waters show the predominance of the Ca^{2+}-Mg^{2+}-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 Na^+ and K^+ as well as the 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 Rooibank

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	**3,050**	3,000	3,100
PCH # 2	5	**660**	250	1,075
PCH # 3	13	**1,000**	320	3,200
PCH # 4	11	**750**	290	2,250
PCH # 5	23	**1,200**	320	3,270
TS # 2/5	6	**1,060**	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^+/K^+	Ca^{2+}/Mg^{2+}	HCO_3^-	Cl^-/SO_4^{2-}
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		HCO3		Cl-SO4	
		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 Na^{+}-K^{+} and Cl^{-} portion on the expense of the Ca^{2+}-Mg^{2+} and 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 % Na^{+}-K^{+} and 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 Na^{+} - 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.