Technical Report Nº Gh 3835

A GROUNDWATER HYDROCENSUS AND WATER QUALITY INVESTIGATION OF THE VERLOREVLEI PRIMARY AQUIFER - ELANDS BAY

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DATE	:	March 1994

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Drainage Region G30

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ABSTRACT

Increasing residential development in Elands Bays requires the augmentation to the existing groundwater source for domestic supply. Following a request by the Elands Bay Local Council, a groundwater and surface water hydrocensus was carried out in March 1993, by the Geohydrology Directorate of the Department of Water Affairs and Forestry, to delineate new groundwater development areas. Two aquifers occur in the area namely an important primary sand aquifer of good quality groundwater overlying a less important, secondary sandstone aquifer.

The hydrocensus showed that the groundwater to the north of Verlorevlei has a markedly better quality than that to the south.

Over-pumping has resulted in localised saline water upconing in the shallow alluvial aquifer. Farming has a detrimental effect, in some areas, by increasing the mineralisation of both the surface and groundwater bodies. Where groundwater abstraction is well managed, such as at the municipal production well-field, the quality remains constant.

Approximately 700 000 m^3 of groundwater is abstracted annually - mostly for irrigation purposes - from the primary aquifer surrounding Verlorevlei.

Two new sites for potential groundwater development are proposed. The most favourable site is considered to be in the area of Bontheuwel farm, along the Elands Bay service road, where the hydrocensus indicated good quality groundwater and surface water, as well as good borehole yields at existing abstraction points.

SAMEVATTING

Toenemende stedelike ontwikkelling in Elandsbaai vereis die ontginning van 'n aanvullende grondwaterbron vir huishoudelike gebruik vir die dorp. Op versoek van die Elandsbaai Plaaslike Raad, is 'n hidrosensus van grond- en oppervlakwaterbronne, in Maart 1993 deur die Direktoraat Geohidrologie van die Departement van Waterwese en Bosbou gedoen teneinde nuwe gebiede vir grondwaterontwikkeling te omlyn. Twee waterdraers kom in die gebied voor, naamlik 'n belangrike primêre sandwaterdraer, wat oor goeie grondwatergehalte beskik, wat op 'n minder belangrike, sekondêre sandsteenwaterdraer rus.

Die hidrosensus het aangedui dat grondwatergehalte noord van Verlorevlei aansienlik beter is as dié suid van die vlei.

Oorontginning het gelokaliseerde souwaterindringing in die vlak alluviale waterdraer veroorsaak. Landbou-aktiwiteit het verhoogde mineralisasie van sommige watervoorkomste, beide grond- en oppervlakwater tot gevolg gehad. Grondwatergehalte bly egter redelik onveranderd waar effektiewe grondwaterbestuur toegepas word, soos dit die geval by die munisipale produksieboorgate is.

Ongeveer 700 000 m^3 grondwater word jaarliks hoofsaaklik vir besproeiing uit die sandwaterdraer in die omgewing van Verlorevlei onttrek.

Twee nuwe moontlike grondwaterontwikkelings-terreine is voorgestel waarvan die mees gunstigste dié in die omgewing van die plaas Bontheuwel langs die Elandsbaai dienspad is. Die hidrosensus het goeie gehalte grond- en oppervlakwater asook goeie boorgatlewerings by bestaande onttrekkingspunte in hierdie omgewing aangedui.

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1 INTRODUCTION

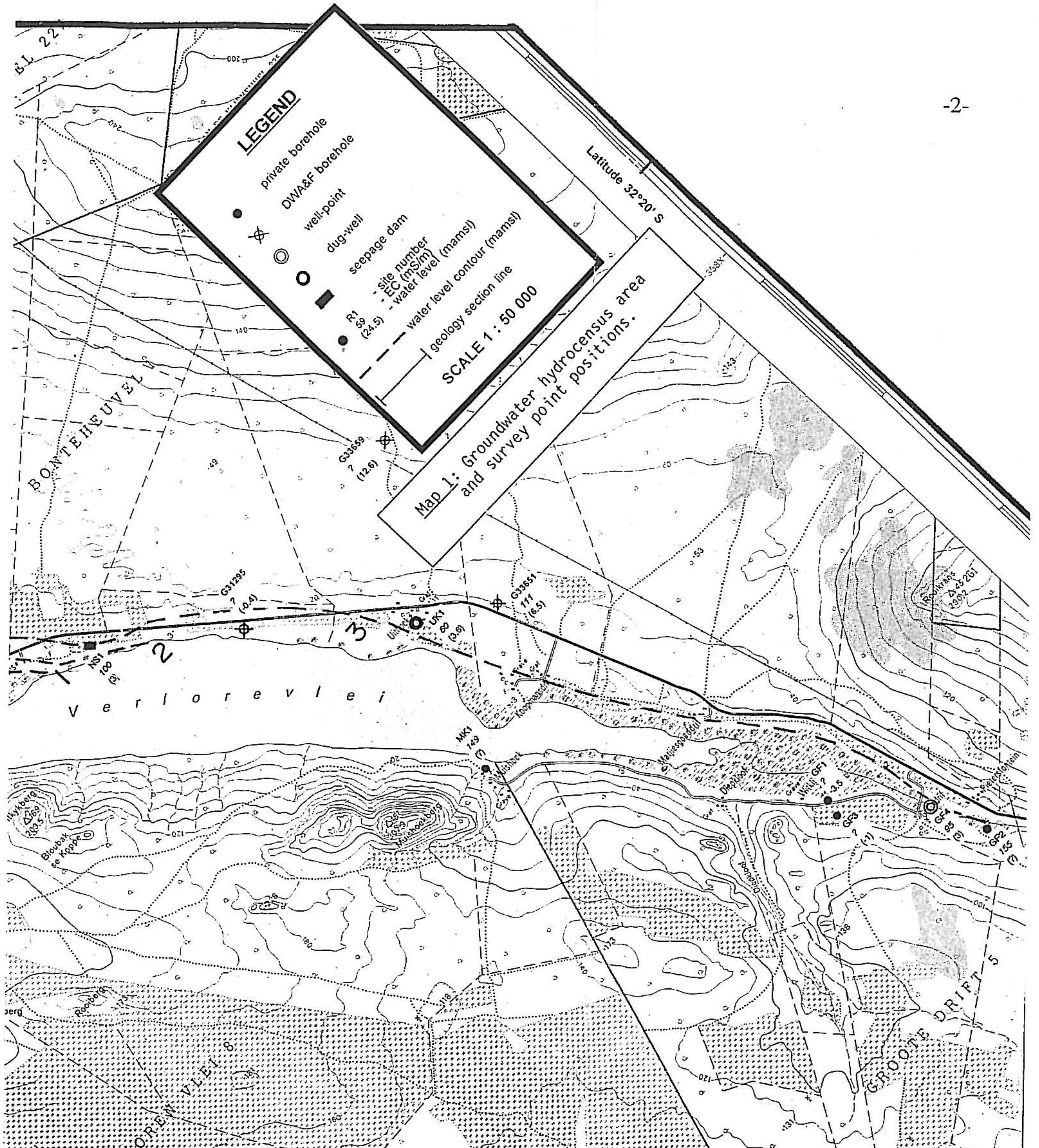
Elands Bay is entirely dependent on groundwater for its domestic water requirements. The groundwater is presently abstracted from a well-field of three production boreholes (R1, R2 and R3 on Map 1) in the Sandveld State Forest, to the northeast of the town. This well-field is presently being pumped at its maximum safe-yield. Increasing residential development pressure on the Elands Bay area has prompted a need to augment the existing domestic water supply to the town. The Geohydrology Directorate of the Department of Water Affairs and Forestry (DWA&F) was approached by the Elands Bay Local Council (EBLC) - in the beginning of 1993 - to assist in an initial survey to delineate potential new areas for groundwater development.

A field-survey was carried out in March 1993 in which a total of 26 groundwater and 11 surface water points was surveyed. The survey was limited to the area immediately surrounding Verlorevlei, so that potential target sites would be near existing road and electricity infrastructure. The hydrocensus gathered information such as water quality, total abstraction, yields and water levels from all groundwater abstraction points in the study area, as well as the quality of Verlorevlei water. This information is summarised in Appendices A and B and the groundwater points surveyed during the hydrocensus are shown on Map 1.

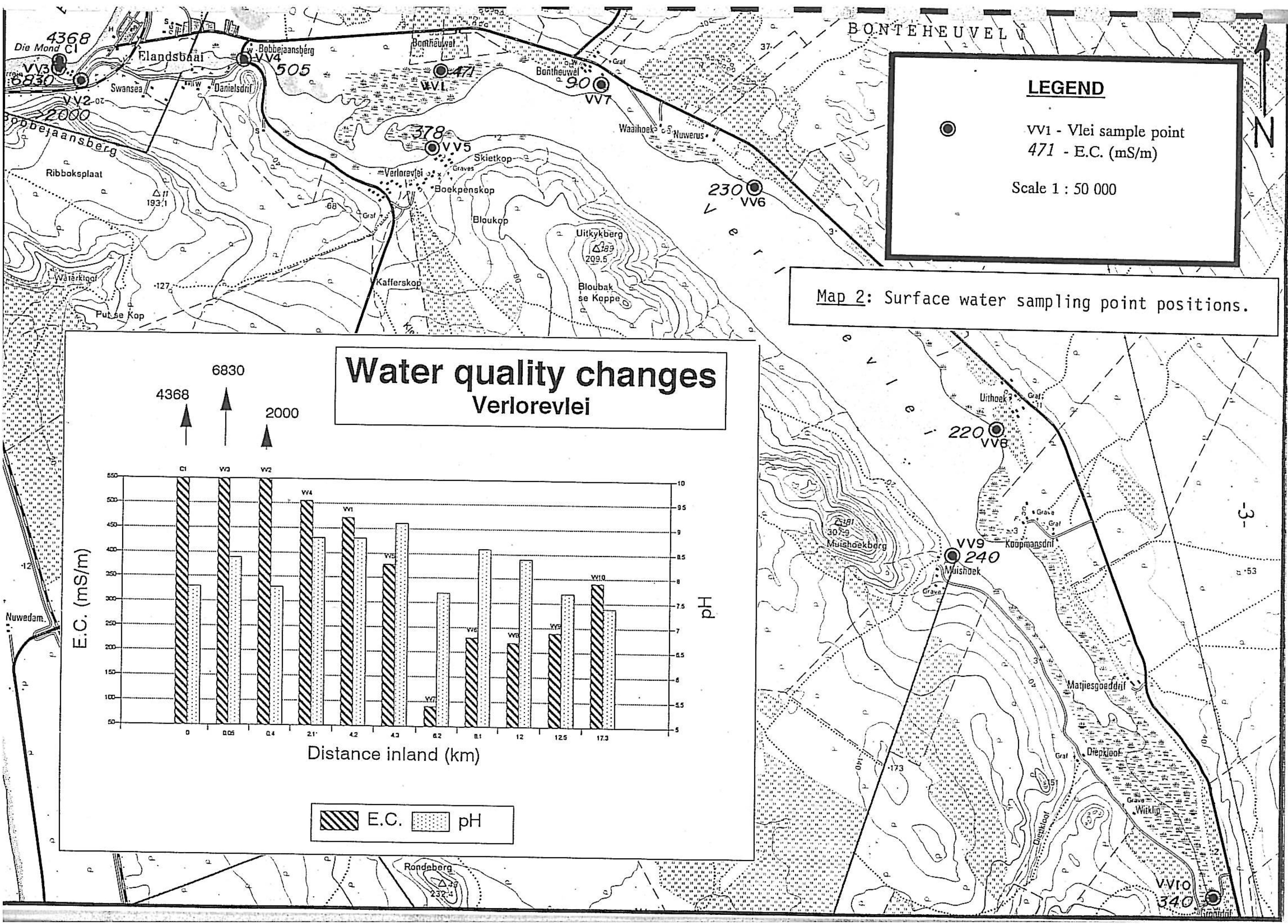
The electrical conductivity (EC) and pH of the groundwater was measured in the field and select water samples were taken for standard macro-analyses. The water quality of the vlei was also monitored in an attempt to assess the base-flow influence of groundwater on the surface water. The vlei sample points are shown on Map 2. The surface and groundwater hydrochemical analyses are summarised in Appendix C.

2 STUDY AIMS

- The delineation of areas where groundwater of acceptable quality for domestic use occurs in the immediate vicinity of Verlorevlei. These areas should be as close to Elands Bay as possible.
- The analysis of the hydro-census results and literature survey to recommend potential areas for further study, as well as advise on the best groundwater resource development method for these areas.



Map 1: Groundwater hydrocensus area and survey point positions.



Map 2: Surface water sampling point positions.

3 TERMS OF REFERENCE

In November 1984, the consulting firm of Lillicrap, Crutchfield, Cragg and Partners recommended the abstraction and treatment of Verlorevlei water for Elands Bay town-supply. This recommendation was accepted by the EBLC. DWA&F, however, suggested that consideration should first be given to the potential of groundwater as a viable source in the area before the exploitation of other more expensive surface-water sources is considered.

Geohydrological consultants SRK Inc. were thus employed by the EBLC to investigate the possibility of developing and exploiting groundwater in the area. A subsequent study carried out in 1985 by SRK - utilising information from DWA&F drilling records and an NPRL geophysical survey - showed the prospect of obtaining a sufficient supply of acceptable quality groundwater to be favourable to the northeast of Elands Bay. This resource was developed in 1986 by drilling 3 boreholes immediately east of DWA&F exploration borehole G31294 shown on Map 1.

One of these boreholes yielded 1.7 ℓ/s and was commissioned as a production borehole. In 1988 DWA&F sited and drilled a further production borehole (G33658A, shown as R3 on Map 1). These two boreholes have been used in combination since 1988 to supply all of Elands Bay's domestic water requirements.

Increasing development of Elands Bay prompted the EBLC, in 1993, to request that the Geohydrology Directorate of DWA&F investigate the possibility of developing an additional groundwater source for town water-supply augmentation purposes. In keeping with the policy regarding assistance to declared water-poor areas (such as the Sandveld), an initial survey was carried out in an attempt to delineate potential areas for further groundwater exploration. This report summarises the findings of this investigation.

4 PREVIOUS INVESTIGATIONS

A synopsis of previous geohydrological investigations carried out in the Elands Bay area is given in Jolly (1992). Of specific relevance to this study are the following:

4.1 SCHREUDER (1978)

This was a hydro-census investigation carried out to gain a review of the groundwater potential in the area between the Berg and Olifants Rivers, to identify possible areas for future development.

Schreuder identified the area east of Elands Bay and north of Verlorevlei (i.e. the topo-cadastral farm of Bonteheuvel 1) as a wide sand-filled basin of good groundwater potential. He based this observation on the low salinity groundwater and good borehole and dug-well yields on the shore of the vlei, as well as boreholes in the higher-lying catchment areas to the north.

4.2. MEYER, et al. (1983)

Meyer, together with other researchers carried out a geophysical and geohydrological investigation of the groundwater potential between Lambert's Bay, Elands Bay and Graafwater. The study aim was to delineate areas of fresh groundwater occurrence in the surficial alluvium covering most of the project area, as well as to determine the extent and thickness of the saturated sand bodies.

Electrical resistivity soundings and exploration boreholes used for correlation identified an area where good quality groundwater occurred northeast of Elands Bay.

4.3 SRK (1986)

This report followed on from an initial investigation carried out by SRK in November 1985 in which two sites of good groundwater potential were identified. A borehole was sited next to DWA&F production borehole G31294 - where the sand had a maximum thickness according to the geophysical investigation carried out by Meyer, et al. (1983).

Drilling and testing produced a borehole yielding 1½ ℓ/s of low salinity groundwater.

5 CLIMATE AND TOPOGRAPHY

Elands Bay is a small fishing village lying on the Atlantic seaboard of the Cape Province, 180 km north of Cape Town.

5.1 CLIMATE

The Elands Bay area is classified as arid. The mean annual rainfall of the area is variable, ranging between 200 and 300 mm, occurring mostly in the winter months of April to September.

A high incidence of advective sea-fog is a feature of the area surrounding Verlorevlei. Since standard rainfall measurements do not record the contribution of fog to total precipitation, the mean annual precipitation (MAP) in the Elands Bay area will be higher than that given in the preceding paragraph.

Strong, frequent winds and a high occurrence of cloud-free days contribute to a relatively high annual evaporation rate (1 150 mm at Lamberts Bay, the closest gauging station).

5.2 TOPOGRAPHY AND DRAINAGE

The study area is characterised by extensive low-lying sand flats which slope gently up to a series of low hills to the north and east of Verlorevlei. A fault-scarp forms the prominent relief feature along a continuous range of sandstone hills immediately south of the vlei.

The soils covering most of the study area are relatively infertile littoral sands of aeolian origin. The area lies at the transition between Karroid and Fynbos vegetation. The prominent vegetation type is Westcoast Strandveld (Sinclair, et al., 1986).

The Verlorevlei River is non-perennial, flowing only during periods of prolonged high precipitation in winter. The river and its feeder tributaries (rising in the Swartberg, Olifantsrivierberge and Piketberg) drain a catchment area of $\pm$ 1 890 km^2.

Several springs occur along the Verlorevlei. Those near the vlei mouth at Baboon Point have very brackish water (Sinclair, et al., 1986).

5.3 VLEI

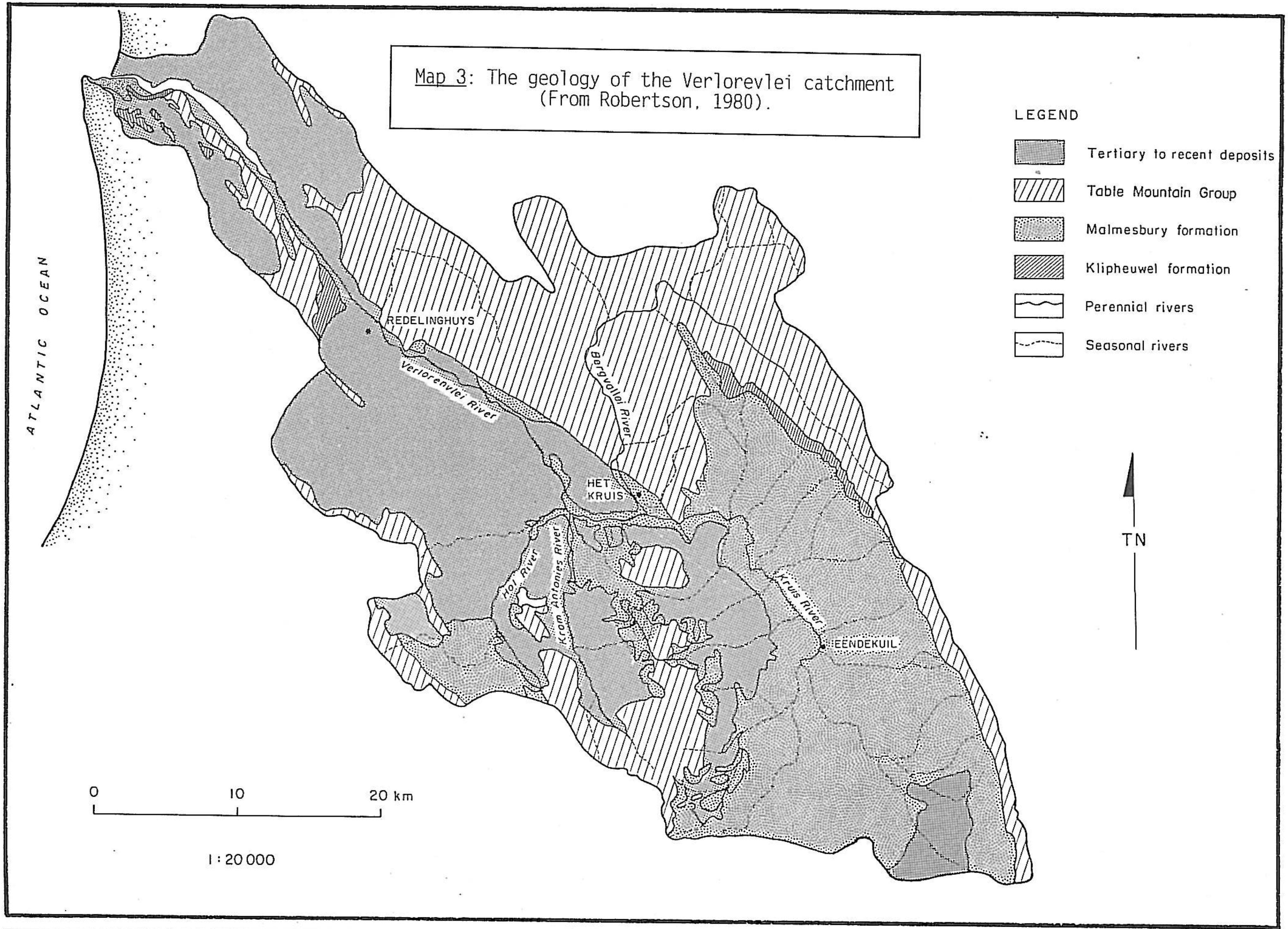
The major drainage feature of the area is the northwest-southeast striking Verlorevlei, which drains seasonally into Elands Bay to the west and is fed by the Verlorevlei River to the southeast. The vlei covers an area of ± 10 km^2 and is 13½ km long and 1½ km wide at its widest point. The water level of the vlei is on average 2 m below mean sea-level (msl), gradually dropping during the dry summer month until it reaches the lowest level in March and April. This is due to losses from evaporation and abstraction for irrigation, as well as reduced inflow from feeder rivers during summer.

Verlorevlei is regarded as a coastal lake, having only an intermittent connection with the sea during extreme storm or tide conditions, or in winter when the vlei fills up and overflows into the sea at Elands Bay. The sand-flats to the north and east contribute seepage water to the vlei as base-flow throughout the year.

6 GEOLOGY

Verlorevlei is situated in a drowned valley which was formed by surface drainage along a northwest trending fault-plane (see Fig. 1). The area has undergone a complex history of submergence and emergence as a result of Pleistocene sea-level fluctuations and early Tertiary tilting of the West Coast (Tankard, 1975). The original vlei flowed out to sea north of the present-day mouth, in the vicinity of Graauw Duinen 234 on Map 1. Withdrawal of the sea left unvegetated tracts of sand exposed which have since been blown into shifting dune fields such as occur north of Elands Bay.

The surface geology of the Verlorevlei catchment - shown in Map 3 - consists mostly of Recent to Tertiary sands comprising 40% of the surface area. Approximately equal proportions of Table Mountain Group (TMG) and Malmesbury Group rocks make up the remaining 60% of the surface outcrops in the catchment.



Map 3: The geology of the Verlorevlei catchment (From Robertson, 1980).

Most of the study area is covered by alluvial Tertiary to Quaternary sand deposits of estuarine-lagoonal facies, overlying predominantly horizontally bedded rocks of the TMG and Klipheuwel Formation (Fm.). Numerous beach terraces near Elands Bay are evidence of past sea-level changes, where the average shore level occurred at 6 m above present sea-level (Tankard, 1975). Along the coast, immediately north of Elands Bay, white shifting sand-dunes extend up to 3 km inland.

The Graafwater and Piekenierskloof Fm.s of the TMG are most commonly encountered below the sand deposits. The Graafwater Fm. consists of characteristically reddish, thinly bedded sandstone, siltstone, mudstone and shale. The basal Piekenierskloof Fm. consists of quartzitic sandstone, with numerous thick lenticular conglomerate bands of vein-quartz pebbles.

The major outcrop in the area is a range of low hills of TMG rocks (Peninsula Fm.) to the south and west of Verlorevlei, comprising white to reddish brown, medium- to coarse-grained massively and commonly cross-bedded sandstone. The Piekenierskloof Fm. outcrops as hills to the north along the Leipoldtville road.

The Cambrian Period Klipheuwel Fm. outcropping in the Verlorevlei area (eg. immediately west of the vlei road-crossing at Danielsdrif farm) consists of poorly bedded, purple to reddish brown sandy micaceous shales. To the south of Verlorevlei, the basal Piekenierskloof Fm. lies unconformably on the Klipheuwel Fm.

Figure 1 is a schematic north-south section indicating the stratigraphic relationship of the area. The position of the section is shown on Map 1.

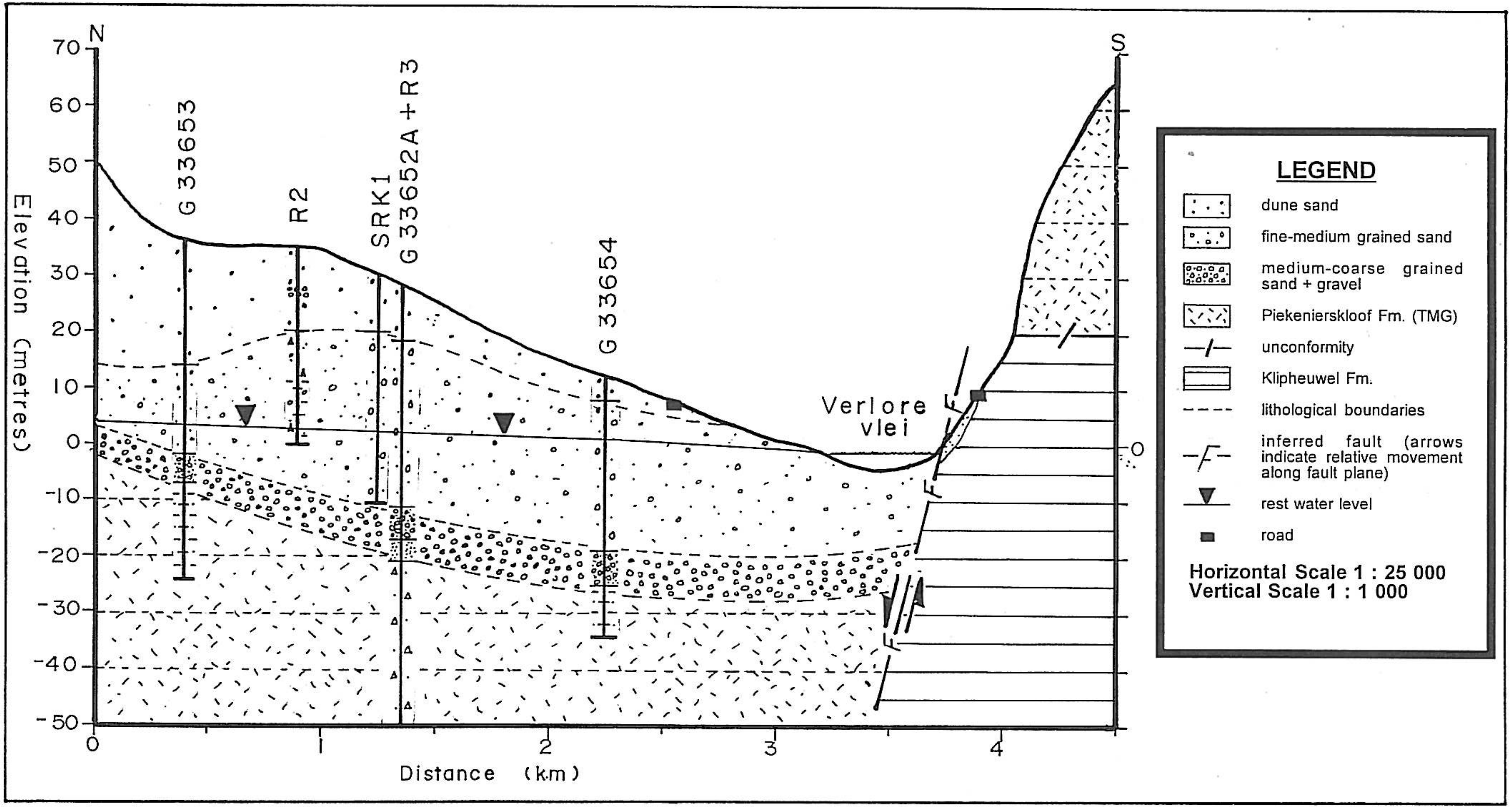


Figure 1: North-south geohydrological cross-section

7 GEOHYDROLOGY

Two aquifer types occur in the area *viz.* an upper, unconfined primary sand aquifer overlying a semi-confined to confined, secondary aquifer consisting of fractured Table Mountain sandstone (TMS).

7.1 PRIMARY AQUIFER

The present well-field is sited on a thick accumulation of sand and gravel deposits northeast of Elands Bay (shown on Map 4) as identified by Meyer, et al. (1983) during their geophysical survey of this part of the West Coast. Other potential groundwater target areas identified in this geophysical survey, such as the 80 m isopach striking northeast from the farm Koopmansdrif, proved to yield only small amounts of relatively brack groundwater with exploration drilling.

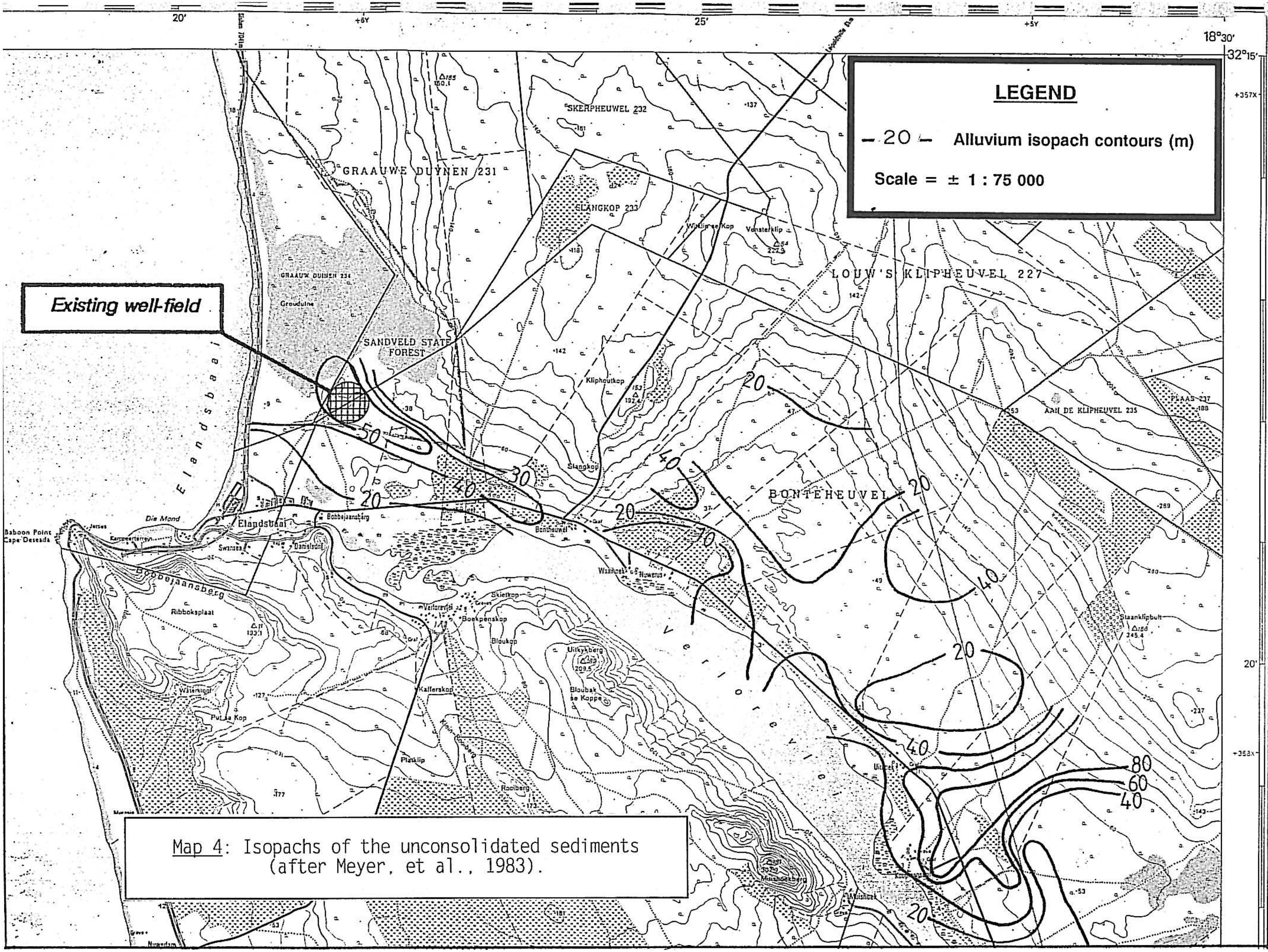
The primary aquifer supplying Elands Bay's domestic water requirements has high groundwater transmissivities and low salinities and occurs as a narrow northwest-trending, sand-filled basin. This basin is considered to be a previous drainage-course of the Verlorevlei River. The palaeo-channel of the River coincides with the 30, 40 and 50 m isopach contours shown on Map 4.

The groundwater in this primary aquifer occurs as a fresh-water lens overlying a more saline water body, with salinity increasing with depth. The geohydrological characteristics of this sand aquifer are summarised in Table 1 below.

Table 1: Primary aquifer characteristics

• aquifer material	-	fluviatile deposits ranging from fine sand to sandy gravel
• aquifer volume	-	34×10^6 m³
• groundwater conditions	-	unconfined to semi-unconfined (leaky)
• saturated thickness	-	15 m
• groundwater storage (S)	-	7×10^6 m³*
• transmissivity (T)	-	350 m²/day (top), 600 m²/day (bottom)
• permeability (K)	-	20 m/day
• specific yield (Sy)	-	0.17
• pumped yield	-	1 - 12 ℓ/s (blow yield 0.1 - 2.5 ℓ/s)
• quality	-	70 mS/m

These figures are based on the average of calculations from localised pump tests carried out on the well-field production boreholes during October 1987, as reported in Jolly (1992), and do not represent conditions for the entire saturated sand aquifer surrounding Verlorevlei.



Map 4: Isopachs of the unconsolidated sediments (after Meyer, et al., 1983).

The medium to coarse grained sand and gravel unit, occurring at the base of the saturated alluvial deposit shown in Figure 1, produces the best groundwater yields. The groundwater-level contours on Map 1 indicate that the major groundwater gradient is shallow westward towards the sea as well as southwest and south towards Verlorevlei. The southward gradient is calculated at a flat 1 : 640 along the north-south line section in Figure 1.

Recharge to the primary aquifer is from runoff from the hill slopes north-east of the Sandveld State Forest Reserve and on the cadastral farm Bonteheuvel 1. Direct infiltration of rainfall incident onto the surface area also recharges the primary aquifer.

Large-scale groundwater abstraction is a cause for concern in the area as it can result in saline water upconing, as well as localised lowering of the water-table. A policy of prudent groundwater management has thus been recommended to the EBLC, by DWA&F and SRK, where groundwater abstraction from the production well-field is controlled within the proven safe-yield of the aquifer.

7.2 SECONDARY AQUIFER

The sea-level changes referred to in Section 6 resulted in the inundation and deep weathering of the TMG and Klipheuwel rocks by sea-water, which remained trapped in the rocks as connate water during diagenesis and lithification. The presence of this connate water was confirmed by Meyer, et al. when their 1983 study found these rocks to contain brackish water.

This secondary aquifer groundwater is generally brack and low yielding, < 1 ℓ/s (Visser, 1969), and is of significance only as a source of saline water upconing or lateral leakage to the primary aquifer.

8 GROUNDWATER USE

Potato farming is the major user of groundwater as seen in Appendix A. Abstraction has increased dramatically in recent years with the introduction of the (agriculturally) successful centre-pivot irrigation system. The main irrigators in the study area are Messrs. T.E.C. Louw (from borehole BL1 on Klein Bonteheuwel) and P.M.A. van Zijl (from boreholes GF2 and GF3 on Grootdrif), who each abstract around 300 000 m^3/yr.

Most farmers' fresh water supply - for domestic and agricultural use - is from dug-wells or seepage dams next to Verlorevlei, or directly from the vlei. A small amount of the total groundwater abstracted is used for stock-watering purposes (mostly sheep with some small dairy herds and localized pig-farming).

The Local Council is the other main groundwater user, abstracting a total of ± 70 000 m^3/yr from 2 production boreholes and 1 standby borehole in the municipal well-field at Sandveld State Forest. This well-field consists of boreholes drilled and tested by DWA&F and SRK. The groundwater is provided for domestic use by the Elands Bay municipality, to a population of ± 1 100 permanent residents - as well as for industrial use in the crayfish factory at Baboon Point. Isolated garden irrigation occurs mostly in the town of Elands Bay.

According to the hydrocensus information, approximately 700 000 m^3 of groundwater is abstracted annually in the study area. The total monthly volumes pumped from the municipal well-field, from July 1990 to February 1994, are shown in Figure 2. It is clear that groundwater consumption is cyclical, with the highest consumptions in the dry summer months also coinciding with the holiday season and resultant influx of tourists to the area.

9 WATER LEVELS

The groundwater-level contours are shown in Map 1 in metres above msl. These contours have been interpolated from reduced water-levels and estimations of site elevations from 1 : 10 000 orthophotos and some inaccuracies will therefore result. The general groundwater-flow gradient is, however, apparent from Map 1.

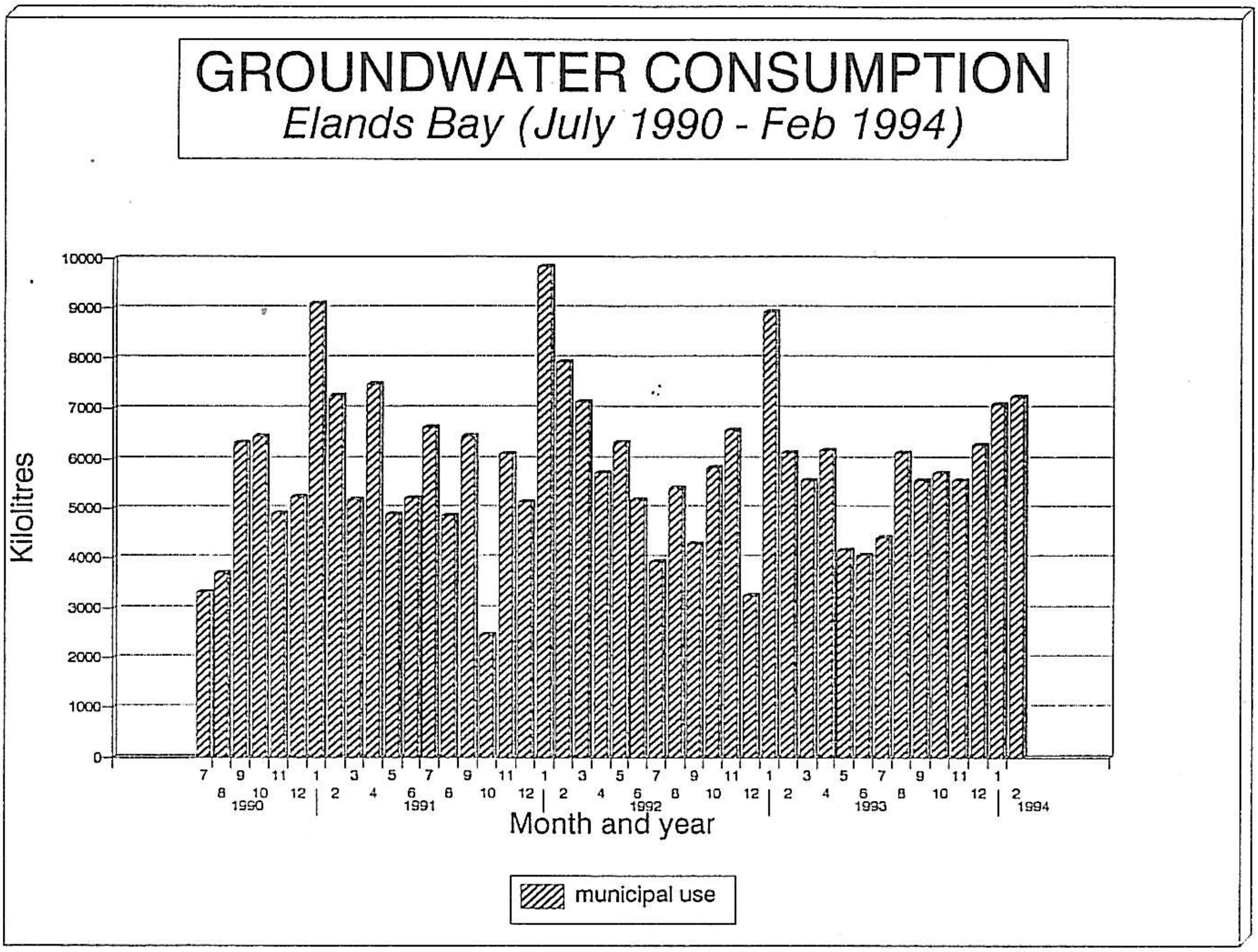


Figure 1: Elands Bay groundwater consumption.

The groundwater-level in the primary aquifer is shallow with an average rest water level around the vlei ± 3½ m below surface (mbs) equivalent to ± 1½ m above msl. This shallow water-table, together with the unconsolidated nature of the water-bearing formation, has encouraged the wide-spread use of dug-wells and seepage dams for groundwater abstraction in the area.

Since the groundwater-level around the vlei is on average only a few metres above msl, it follows that most of the sand aquifer lies below sea-level. This is significant regarding sea-water intrusion if over-abstraction occurs, specifically in the westernmost (seaward) portion of the aquifer.

Throughout the year Verlorevlei is a gaining system (i.e. it is recharged by groundwater) since the vlei-water levels are on average ± 2 m below msl (Sect. 5.3) compared with an average groundwater-level of 1½ m above msl (Sect. 9).

In contrast to the rest of the study area, the water level below the production boreholes (R1, R2 and R3) is deep, lying ± 25 metres below surface i.e. ± 1½ m above msl. This is a function of the relatively high collar elevation of these boreholes, compared with the other groundwater abstraction points around the banks of the vlei.

10 WATER QUALITY

10.1 SURFACE WATER

Since Verlorevlei is the dominant surface water feature in the study area, and it is hydrologically connected to the groundwater, its water quality aspects are considered important. Geology has an important influence on the quality of water entering the vlei. Water draining the TMS is low in mineral salts and slightly acidic, whereas the Malmesbury Group rocks - which underlie more than 30% of the catchment (Map 3) - contain high salt concentrations that leach slowly into the groundwater and streams with progressive weathering, to produce brackish water.

The average EC for the 8 Verlorevlei water samples surveyed in this study (Appendix B and C) is 309 mS/m. Sampling positions are shown on Map 2. The graph on Map 2 confirms Robertson's 1980 finding that there is a salinity decline with increasing distance inland (southeastward) along the vlei. Although the surface water samples (VV1-10) taken for this study do not accurately represent the quality of the vlei water (since a degree of mixing of vlei- and groundwater occurs in the shallow water body along especially the northern banks of Verlorevlei) a definite trend is apparent.

Verlorevlei's estuarine channel mouth is usually closed by a sandbar and man-built channel obstructions, reducing it to a series of stagnant hyper-saline pools during the summer droughts. The hydrocensus was carried out in late March, i.e the end of the dry season, and the effects of evaporation on the vlei were noticeable (Vlei sample VV3 had an EC of 6 830 mS/m - almost one and a half times that of sea-water).

During heavy winter rains the sandbar at the vlei mouth is periodically breached allowing tidal interchange with sea-water that penetrates some 4½ km inland. During winter the vlei water becomes almost fresh as a result of the increased inflow from the rivers recharged by rain as well as base-flow from groundwater.

Of interest is the anomalously low EC at vlei sample point VV7 (90 mS/m). Field observation could not determine any topographic or drainage feature that would explain this phenomenon. It is postulated that this is an area of a high rate of base-flow infiltration of good quality groundwater into the vlei. The observed low conductivity of the well-point and dug-well samples (average EC of 115 mS/m for BH3, BH4 and BH6), in the immediate vicinity of VV7, supports this statement.

10.1.1. The effect of farming on surface-water quality

There is extensive wheat and potato cultivation in Verlorevlei's catchment area and the associated ploughing of the Malmesbury-derived soils exposes the soil surfaces to weathering. This increases the release of salts, especially sodium (Na^+) and chloride (Cl^-), which are the major ions leached from the Malmesbury Group. A further concern associated with cultivation of the area, is the use of the centre-pivot irrigation method that further accelerates the leaching of salts, fertilizers and herbicides into the groundwater system.

10.1.2 Piper Diagram

The Verlorevlei water is a sodium-chloride type, with a trend towards a sulphate type in the anion field - as shown by the plotting positions on the Piper Trilinear Diagram in Figure 3.

The sample points are well clustered indicating a similar origin. The ionic ratio is comparable to that of sea-water, to be expected with tidal inflow into the vlei during winter and groundwater seepage during dry summer periods.

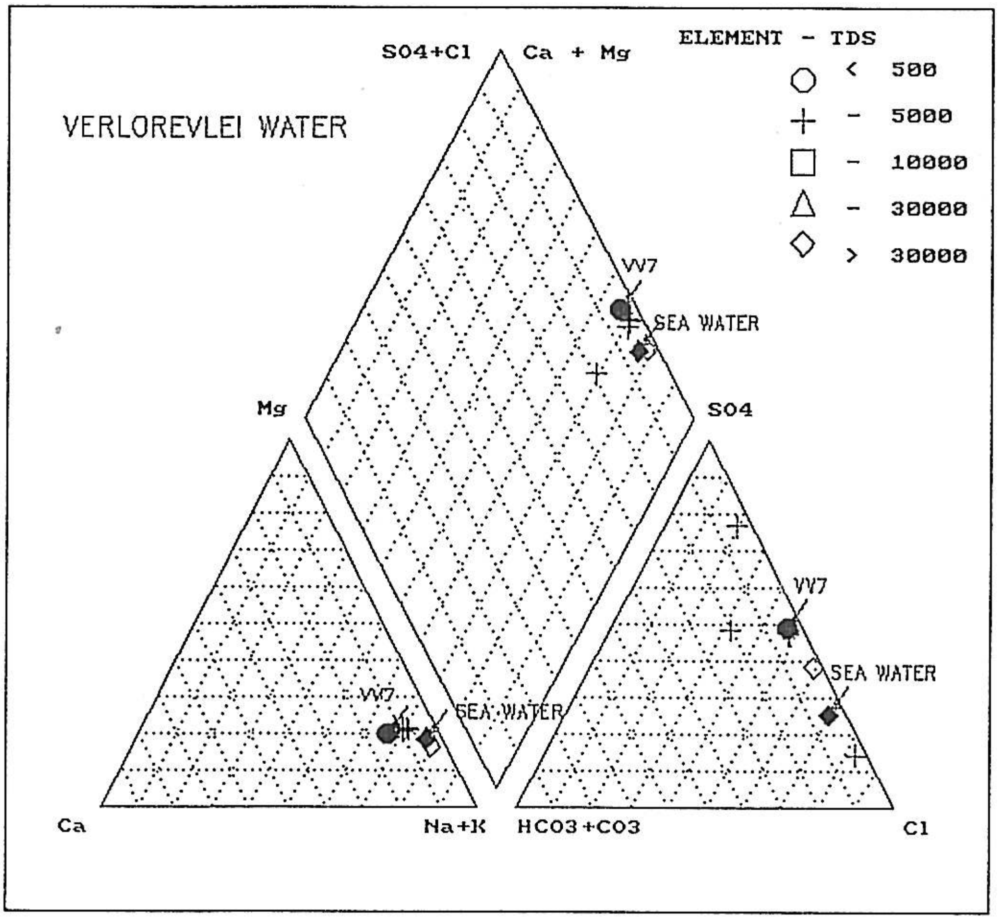
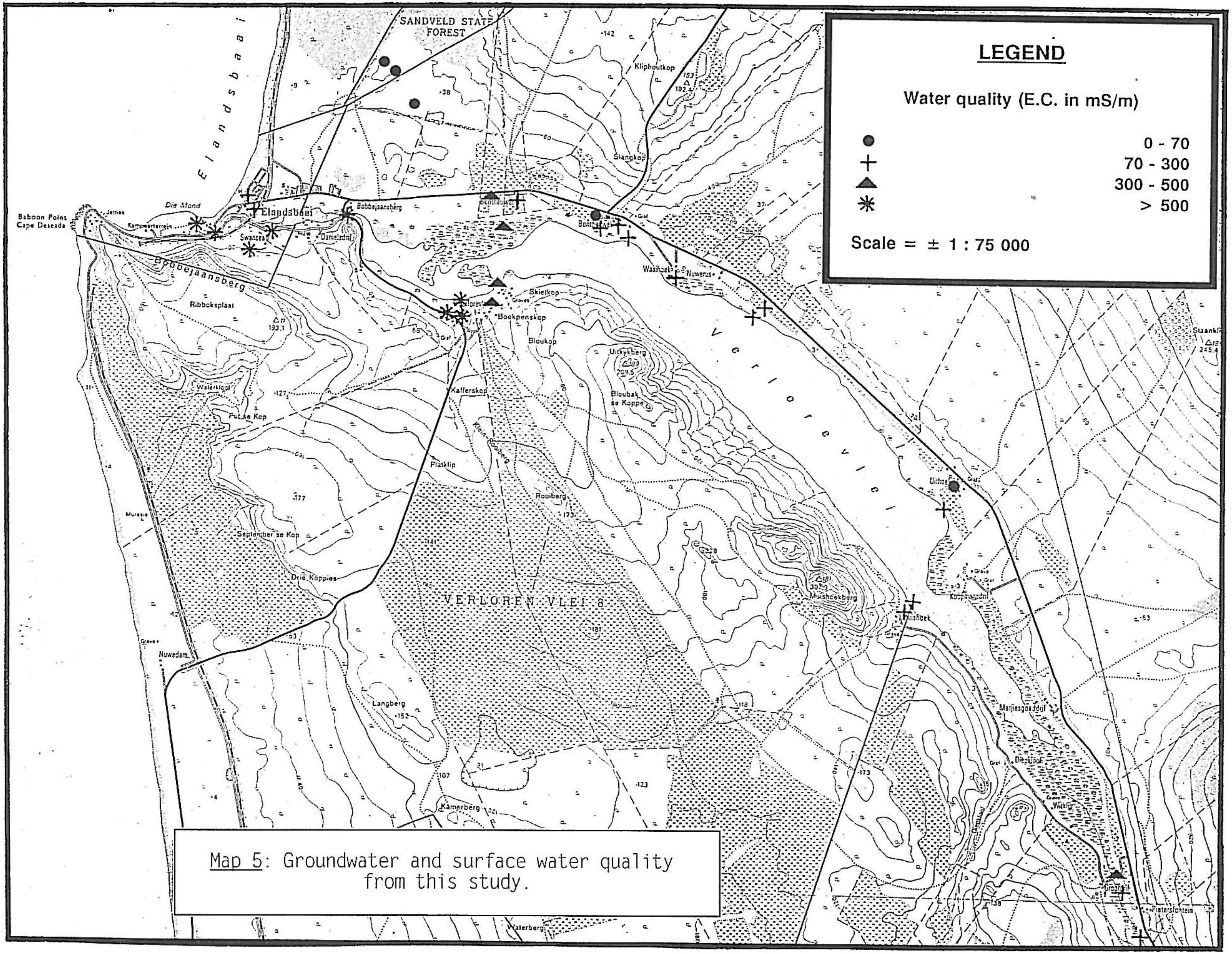


Figure 3: Piper plot of Verlorevlei water.

The TDS values generally fall in the 2 000 - 3 000 mg/ℓ range, classifying the water as brackish according to Freeze and Cherry (1979). The vlei sample point VV7 is a Na-Cl type water, although its TDS value of only 422 mg/ℓ classifies it as fresh.

10.2 GROUNDWATER

The groundwater quality analyses for the 19 samples taken during the survey (Map 1) are presented in Appendix C. Perusal of Table 2 and Map 5 reveals that groundwater to the south of Verlorevlei - especially in the vicinity of Verlorevlei farm - is much more saline than north of the vlei. This is considered to be a function of differences in depth and extent of the sand-covered catchment areas (shown schematically in Figure 1) as well as differing intensities of land-use north and south of the vlei (discussed further in Sect. 10.2.1).



Map 5: Groundwater and surface water quality from this study.

Since the silica sand deposits have inherently relatively small concentrations of salts compared with the TMG sandstones and Klipheuwel shales, a higher permeability and thus shorter groundwater residence times, as well as a natural filtering ability of the sand, it follows that groundwater derived from these deposits will have a lower total dissolved salt concentration and thus lower salinity.

A further physical aspect of significance explaining the difference between the groundwater qualities north and south of the vlei, is a function of the different soil-types encountered in these areas. The soil type south of Verlorevlei has a relatively high clay content which will result in the flushing of salts into the groundwater zone with leaching. The soil of the northern catchment area, in contrast, produces less saline water with leaching, as a result of its predominantly well-washed silica sand content, resulting in a low reserve of weatherable minerals and a low silt/clay ratio (Sinclair, et al., 1986).

Table 2: Summary of groundwater hydrocensus.

Site type	Number of sample points		Av. EC (mS/m)		Av. pH	
	† N	S	N	S	N	S
Borehole	**5**	**5**	**127**	**411**	**6.8**	**6.6**
Well-point	**2**	**2**	**115**	**562**	**6.4**	**6.5**
Dug-well	**7**	**3**	**158**	**626**	**7.4**	**7.5**
‡ **Dam**	**1**	**1**	**100**	**630**	**7.1**	**8.1**
Area average	**15**	**11**	**125**	**557**	**6.9**	**7.2**

† *sample point areas north (N) and south (S) of Verlorevlei*
‡ *dam water is seepage groundwater*

The pH of the study area groundwater is generally neutral, with the northern groundwater being slightly more acidic than the southern groundwater. The reasons for this are not immediately clear but could be a function of the different lithology of the source rock which produced the alluvium as well as varying degrees of leaching (Whittow, 1984) in the northern and the southern catchments.

Both Meyer, et al. (1983) and Jolly (1992) describe the phenomenon of an increase in groundwater salinity with depth in the alluvial aquifer. This is considered to be a function of density stratification where fresh groundwater occurs as a lens overlying a more dense, saline groundwater body. This has important implications regarding aquifer management where over-abstraction from the aquifer can result in contamination of the fresh groundwater by upconing of the saline water. This is discussed further in 10.2.1.

An area of better than average water quality occurs at Bonteheuwel farm (Map 5 and Appendices A, B and C), at the junction of the Leipoldtville Road with the Elands Bay servitude road. It is assumed that a relatively extensive body of good quality groundwater occurs in this region (explained in Section 10.1), but this can only be confirmed with further exploration drilling. This area is considered of importance for groundwater development in the future (see Section 11.1).

Figure 4 shows that the groundwater conductivities from the production boreholes used for town supply, have remained relatively constant at an average EC of 59.8 mS/m over the 5 year time period monitored, i.e. June 1988 to July 1993.

10.2.1 The effect of farming on groundwater quality

Extensive agricultural activity (ploughing, irrigation and fertilizer application), south and up-gradient of Verlorevlei, further accounts for the highly saline groundwater of the southern catchment area, as a result of increases in the rate and amount of salts leached. The average EC for Verlorevlei farm groundwater samples Vl1-Vl4 is 727 mS/m.

According to Heydenrych (1993), 8 new centre-pivot circles have been cleared and developed for planting since 1986 in the Verlorevlei farm area alone. Aquifer salinisation may occur in the near future, as increasing agricultural development places expanding pressures on the land and water resources.

Over-pumping of the aquifer has already occurred on Bontheuwel farm (at BL1 and BL2) resulting in localised saline water upconing into the overlying

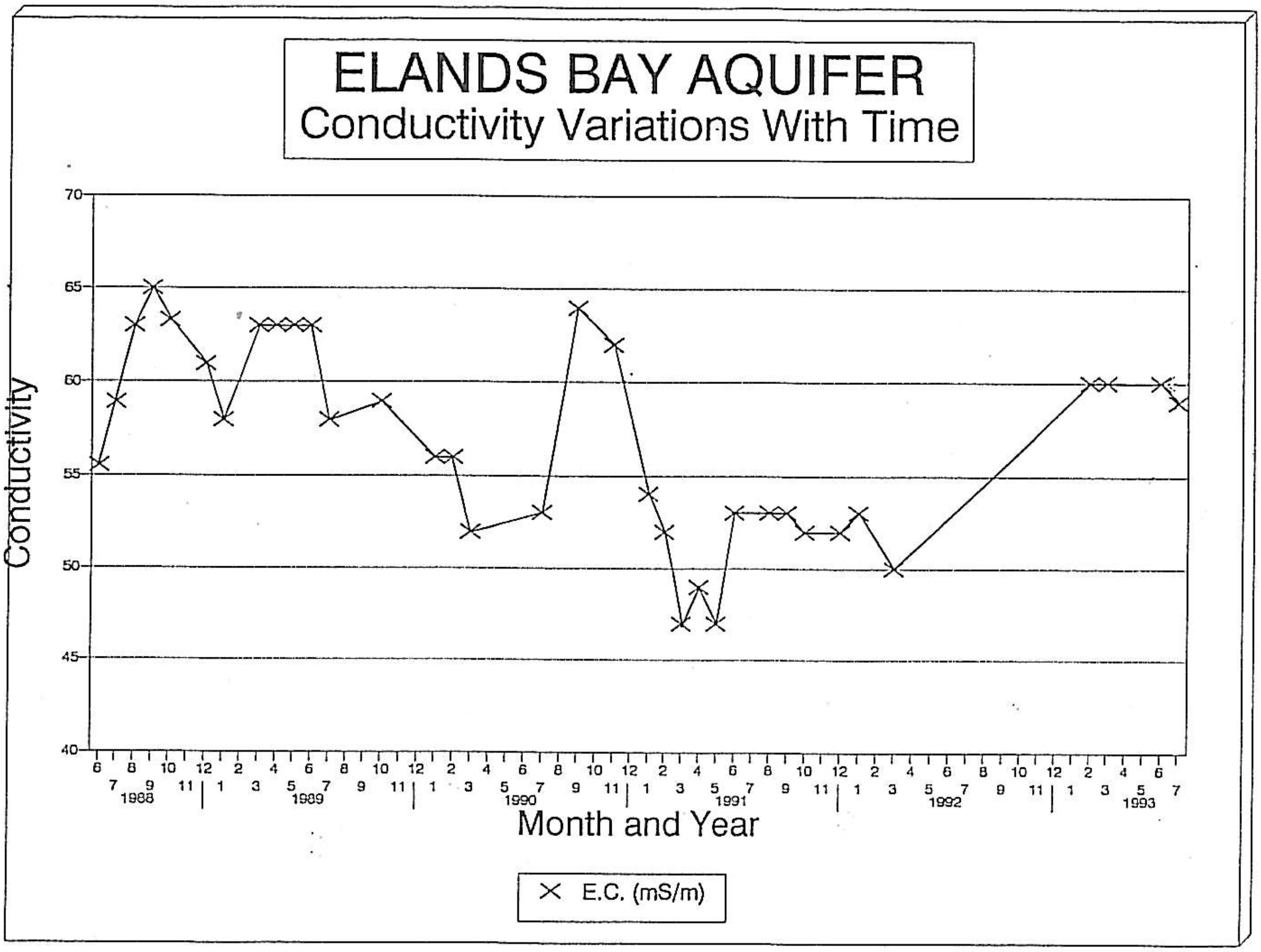


Figure 4: Groundwater conductivity variations with time at the Elands Bay production well-field (boreholes R1-3).

fresh-water body. The farmer is, however, aware of the situation and is taking steps to prevent the recurrence of this condition in the future.

10.2.2 Piper Diagram

The primary aquifer groundwater - sampled mainly around the banks of the vlei - is a sodium-chloride to sodium-sulphate type water of relatively mixed origin, shown in Figure 5. The groundwater plots in the same area as the vlei-water, indicating similar origins and that it is recharging the vlei water.

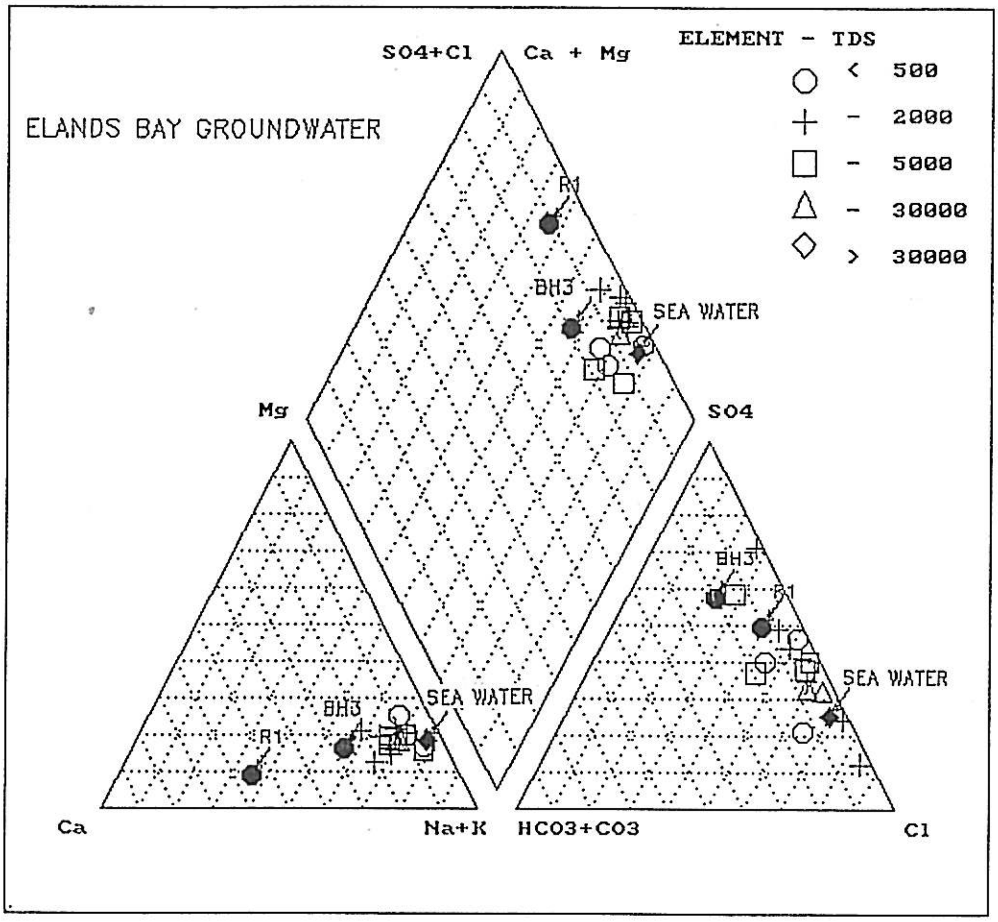


Figure 5: Piper plot of Elands Bay groundwater.

The TDS concentrations ranging from 500 to 3 500 mg/ℓ, classify the groundwater as fresh to brackish.

The plotting position of production borehole R1 suggests mixing. This is probably a function of the depth of abstraction of ± 25 metres below surface, where older deeper circulating alluvial groundwater is being sampled (compared with ± 3½ mbs for the other sampling points as seen on Map 1).

10.3 FITNESS FOR USE

The aim of the study was to survey the occurrence and quality of groundwater in the alluvial aquifer surrounding Verlorevlei and to identify areas of potential future groundwater abstraction. Certain sampling points were thus selected for full macro analyses to determine the **general** fitness for use for domestic purposes. The results of the analyses are shown in Appendix C. The failing determinants, i.e. those with concentrations exceeding the accepted water quality guidelines and standards as outlined in Appendix C, are highlighted.

Of the 19 groundwater samples on which macro analyses were carried out, only 7 (or 37%) are fit for use. Only 1 vlei sample (VV7) out of a total of 6 analyzed (i.e. 17%) is considered fit for use. The very low pH (5.7) of VV7 is considered as unrepresentative, since it is a laboratory- and not a field-measurement, and is therefore disregarded.

The most commonly failing determinants are the Na^+ and Cl^- ions (and therefore the EC and TDS), for reasons explained in Section 6 dealing with catchment characteristics.

The high phosphate (PO_4) concentrations in the groundwater are a result of the prevalence of low grade marine phosphatic sediments and sands, on the coastal plain and farms north and northeast of Elands Bay respectively. These sediments release phosphate to the groundwater with leaching during weathering.

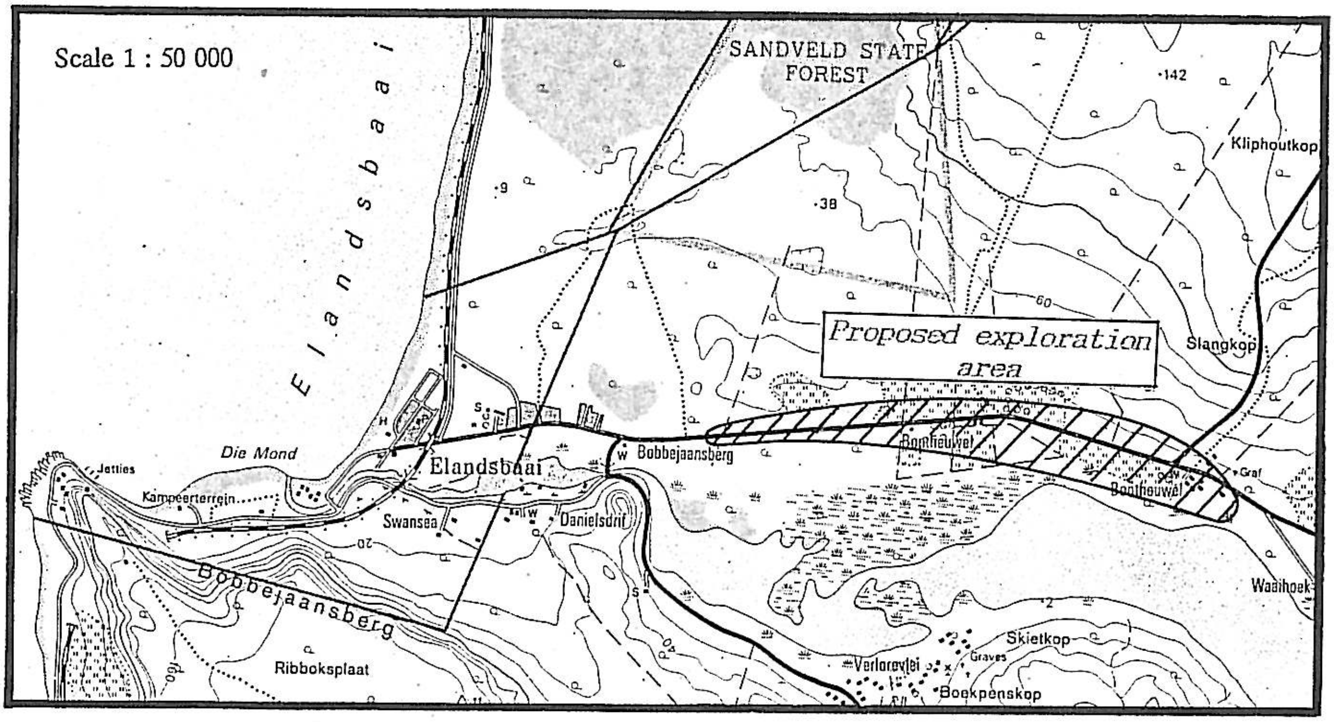
The high nitrate (NO_3) concentrations occur mostly down-gradient of cultivated lands, in which fertilizer is applied directly to the lands or indirectly via the irrigation water through centre-pivots (fertigation). This may also explain the high phosphate concentrations in some areas, since PO_4 is a component of agricultural fertilizer. High NO_3 also occurs around areas of livestock accumulation (eg. at the farm Boekpenskop), giving rise to typical "barnyard" pollution.

The high magnesium (Mg) concentrations are associated with the sporadic, evaporitic brine deposits of magnesium and calcium carbonate in the area, as well as the occurrence of Mg in solution in irrigation drainage water. Magnesium also occurs as a major ion in sea-water, which was trapped as connate water in the sands of the area as explained in Section 7.

11 RECOMMENDATIONS

Based on the findings of the hydrocensus, two sites for further exploration are identified :

11.1 BONTHEUWEL FARM



Map 6: Location of proposed groundwater exploration area - Bontheuwel farm.

This target region lies immediately east of Elands Bay and is indicated as a hatched area on Map 6. It forms part of the cadastral farm Bonteheuvel 1.

The area is considered favourable for the following reasons :

- proximity to Elands Bay requiring only a 2 - 4 km pipeline
- abstraction could take place within the road servitude thus negating the need to expropriate private water rights
- existing infrastructure i.e. road and electricity
- relatively good quality groundwater (± 115 mS/m) and vlei water (90 mS/m)
- high-yielding borehole BL1 in the region (± 18 ℓ/s).

The geohydrological potential of the area will have to be confirmed - by exploration drilling - before a decision is made to carry out development of the production phase.

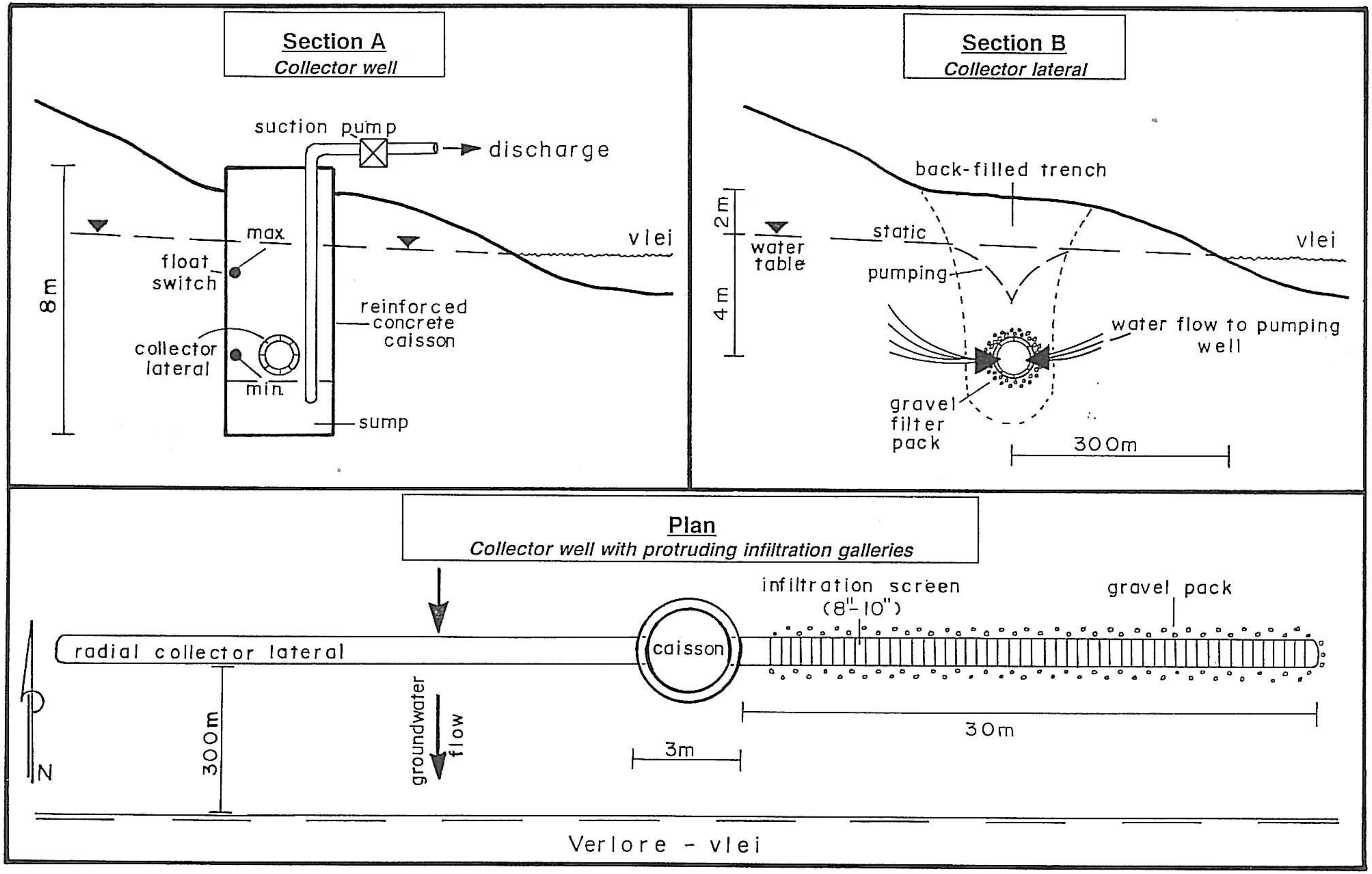


Figure 6: Schematic design and layout of a collector well system

11.1.1 Groundwater abstraction method

It is proposed that this potential groundwater abstraction area is favourable for the development of a collector well type system, as shown in Figure 6, mainly as a result of the shallow water table. This abstraction method consists of shallow, horizontal radially-projecting, infiltration galleries (or collector laterals), which drain to a large diameter well constructed out of reinforced concrete caissons. This groundwater abstraction method has been successfully and extensively employed both locally (eg. Port Alfred, Kleinemond, Albertina and Garies) and internationally (eg. Zimbabwe, Malawi, Sri Lanka and the United States).

Advantages of this collector well method are :

- yield is generally much greater than for a dug-well or slim borehole (Ball, et al., 1992)
- significant storage can be contained in the large diameter central shaft or caisson
- low pumping drawdown with a wide and shallow cone of depression and quick recovery after pumping (Wright, 1988)
- the possibility of salt-water upconing is reduced because of low drawdown
- as a result of small drawdowns and shallow water levels, centrifugal suction pumps - which are cheaper than submersible pumps - can be used for abstraction
- lower development and maintenance cost than conventional vertical wells or boreholes
- low environmental impact (WWI, 1989).

Disadvantages of this method are :

- fine sand and silt can block the screens, but this can be overcome with correct screen-slot size and gravel packing as well as routine back-washing to flush out fines
- incorrect design of the radial well construction results in failure of the scheme

Considering the facts presented above, the shallow water-table in the Bontheuwel farm area (3 - 4 mbs), the aquifer material's unconsolidated nature, as well as the occurrence of the fresh groundwater as a lens "floating" on more saline groundwater (Jolly, 1992), make for ideal conditions for the application of this collector well system, as opposed to a conventional system of vertical boreholes.

The likelihood of more saline vlei water entering the groundwater system to be exploited by the collector well is discounted since:

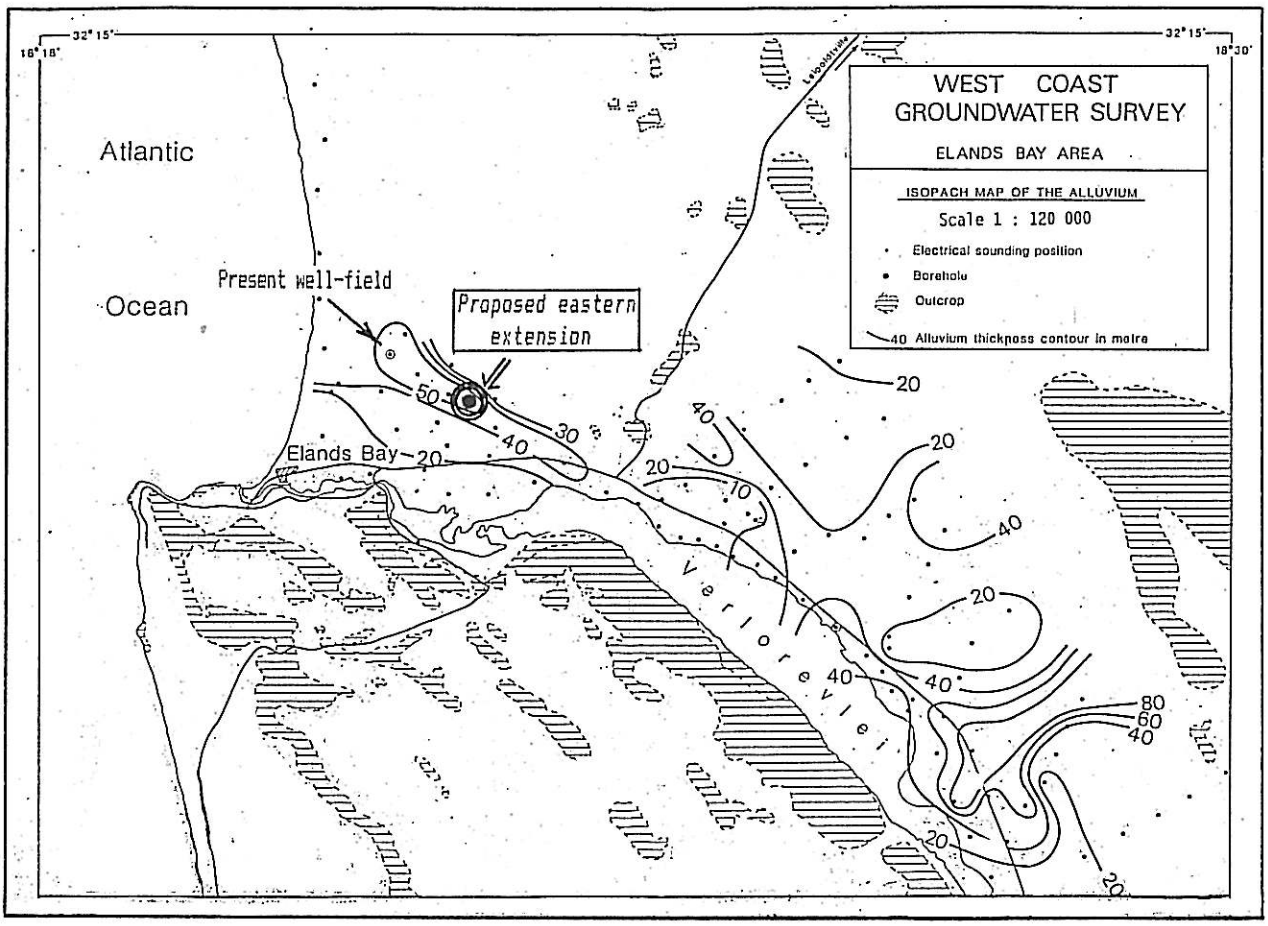
- the groundwater flow direction and gradient is south towards the vlei (the vlei is a gaining system),
- the collector well is proposed to be sited ± 300 m away from the vlei to the north, and
- the radial collector laterals will be at a depth of only ± 6 mbs i.e 4 m below the water-table.

11.2 SANDVELD STATE FOREST

This target site is marked with a circle on Map 7. It is proposed to locate a fourth borehole east of R3 thus forming an extension to the existing municipal production well-field. The target area is identified in the geophysical study of Meyer, et al. (1983) and is based on isopachs of the unconsolidated sediment (shown on Map 4 and 6), indicating an alluvial package thickness here of 40 - 50 m.

It is unlikely that this borehole will yield significantly more water than the present production boreholes; and will probably yield less, since the sediment package is not as thick as that below the production boreholes further to the west. A further point for consideration is the fact that most of this primary aquifer lies below sea-level (as outlined in Sect. 9). As a result, increased abstraction from this aquifer could result in sea-water intrusion, with detrimental effects on the quality of the groundwater abstracted for domestic consumption.

In order not to encroach on the private land of cadastral farm Bonteheuvel 1, any new borehole drilled in the Sandveld State Forest area will have to be sited relatively close



Map 7: Proposed eastern extension to existing well-field (after Meyer et al., 1983).

to the existing well-field. This could cause well interference. The lack of existing infrastructure such as electricity, roads or a pipeline extension east of the present well-field, also causes a logistical problem that will have to be overcome if this area is considered for groundwater development. The installation of this infrastructure has obvious economic consequences.

11.2.1 Groundwater abstraction method

The only feasible method of groundwater abstraction in this area of shifting dunes and relatively deep water-table, is an extension to the existing well-field. This will require the drilling of one or more boreholes equipped with submersible pumps and linked to the existing piping infrastructure.

11.3 WADRIF GROUNDWATER

A further option for water supply augmentation to the existing scheme is "importing" groundwater from the Wadrif aquifer, approximately 10 km to the north. This is not considered possible, however, since the Wadrif aquifer is already over-utilised, supplying water to Lambert's Bay as well as to farmers in the Wadrif area for irrigation. A DWA&F water balance carried out in March 1994 showed that groundwater abstraction in 1991 already exceeded aquifer recharge by approx. 1.3×10^6 m^3/yr. The piping distances involved to connect Elands Bay to Wadrif would also make this option uneconomical.

12 CONCLUSION

Two aquifers occur in the area *viz.* a shallow unconfined primary sand aquifer and a deeper semi-confined to confined hard-rock aquifer. The primary aquifer contains fresh to slightly brack groundwater (EC's of 100-150 mS/m). The secondary aquifer has poor quality, connate groundwater. The primary aquifer groundwater is a sodium-chloride to sodium-sulphate type and is generally less saline north of Verlorevlei than south. The vlei water is a sodium-chloride type. An area of anomalously low salinity vlei water was identified on Bontheuwel farm. It is proposed that this is an area of fresh groundwater inflow to the vlei. This needs to be investigated further.

Only 7 of the 19 groundwater samples and 1 of the 6 vlei samples analyzed were fit for domestic consumption. The major failing determinants were the high concentrations of the sodium and chloride ions. Farming practises were observed to have a noticeable detrimental effect on the quality of both the groundwater and the vlei water in certain areas, generally causing increased salinity. The quality of the well-field groundwater has remained static at approximately 60 mS/m since 1988.

The total volume of groundwater abstracted annually in the study area is ± 700 000 m^3, of which ± 600 000 m^3 is used for centre-pivot irrigation purposes - mostly for potato farming. The remaining 100 000 m^3/yr is used for domestic and stock-watering purposes. Large-scale over-abstraction has resulted in local incidences of saline water upconing such as has occurred on the farm Bontheuwel.

The primary aquifer is recharged by precipitation and infiltration of runoff from the catchment area. The groundwater flow gradient is southward towards Verlorevlei and westward towards the sea. The average groundwater-level in the primary aquifer is 1½ m above mean sea-level, whilst the water level of Verlorevlei is on average 2 metres below sea-level, making the vlei a gaining system.

Two new sites for groundwater exploration are identified. In order of preference they are: the design and construction of a collector well system, next to the Elands Bay service road, in the Bontheuwel farm area; or an eastern extension of the existing production well-field, utilising conventional vertical boreholes for groundwater abstraction. Both these sites will have to be explored further by means of drilling before a final decision on implementation can be reached.

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SA 1 : 250 000 Geological Sheet	3218 Clanwilliam
SA 1 : 125 000 Geological Sheet	3118C - Doringbaai 3218A - Lamberts Bay

APPENDIX A

GROUNDWATER HYDROCENSUS DATA

LEGEND

Site type	:	DW	-	dug-well
		BH	-	borehole
		WP	-	wind-pump
		D	-	seepage dam
		V	-	vlei
		S	-	sea
Latitude + Longitude	:	D M S	-	degrees minutes seconds
Elevation	:	mamsl	-	metres above mean sea-level
Water use	:	D	-	domestic
		G	-	garden
		I	-	irrigation
		Ip	-	potato irrigation
		M	-	municipal supply
		N	-	none
		S	-	stock-watering
		W	-	workshop
Pump type	:	C	-	centrifugal
		N	-	no pump
		S	-	submersible
		W	-	wind-pump
Yield + abstraction	:	estimations in ℓ/s and rounded off to nearest 5 m^3/yr respectively		
EC	:	shaded values exceed maximum recommended limit for domestic use		
pH	:	field measurement (varies from laboratory measurement in Appendix B)		
Water level	:	mbs	-	metres below surface
Date	:	date of site visit		

SITE ID.	SITE TYPE	OWNER CADASTRAL FARM FARM NAME	LATITUDE (D M S)	LONGITUDE (D M S)	ELEVN. (mamsl)	WATER USE	PUMP TYPE	YIELD (l/s)	ABSTRACT -ION (m3/yr)	E.C. (mS/m)	pH	GEOLOGY	WATER (mbs)	LEVEL (mamsl)	BH DEPTH	DATE
BH3 3218 AD	DW 98	A.J.A. LOUW BONTEHEUVEL 1 Klein Bontheuwel	32 18 53	18 23 46	7	D G I	W	0.07	2 190	51.1	7	sand	6.45	0.55	10	93-3-24
BH4 3218 AD	DW 97	A.J.A. LOUW BONTEHEUVEL 1 Klein Bontheuwel	32 18 55	18 23 47	3	G	C	?	?	180	10.2	sand	?	?	?	93-3-24
BH5 3218 AD	BH 96	A.J.A. LOUW BONTEHEUVEL 1 Klein Bontheuwel	32 16 55	18 24 51	172	S	W	0.3	wind dependent	101.2	6.1	sand (8m) clay TMS	?	?	84	93-3-24
BH6 3218 AD	WP 95	N.P. SIMSON BONTEHEUVEL 1 Bontheuwel (Verlore Vlei Holiday Inn)	32 18 56	18 23 56	4	D G	C	?	?	115	6.4	sand	2.09	1.91	10	93-3-25
BH7 3218 AD	WP 94	N.P. SIMSON BONTEHEUVEL 1 Bontheuwel (Verlore Vlei Holiday Inn)	32 18 55	18 23 51	5	D G	C	?	?	?	?	sand	?	?	10	93-3-25
BL1 3218 AD	BH 93	T.E.C. LOUW BONTEHEUVEL 1 Klein Bontheuwel	32 18 43	18 22 42	4.5	I	S	17.7	298 670	356	6.6	?	2.96	1.54	21	93-3-24
BL2 3218 AD	DW 92	S.S. BARNARD BONTEHEUVEL 1 Klein Bontheuwel	32 18 43	18 22 55	5.5	D G	C	?	3 370	212	6.6	?	5.3 pumping	0.2	?	93-3-24
GF1 3218 AD	BH 91	P.M.A. VAN ZYL GROOTE DRIFT 5 Grootdrif	32 23 29	18 27 59	3	N	N	6	0	?	?	sand (3m) TMS	6.44	-3.44	100	93-3-26
GF2 3218 AD	BH 90	P.M.A. VAN ZYL GROOTE DRIFT 5 Grootdrif	32 24 23	18 28 39	15	Ip	S	15	58 920	155	6.2	sand (3m) TMS	?	?	100	93-3-26
GF3 3218 AD	BH 89	P.M.A. VAN ZYL GROOTE DRIFT 5 Grootdrif	32 23 32	18 27 58	6	Ip	S	23	235 665	?	?	sand (2m) TMS	7	-1	100	93-3-26
GF4 3218 AD	WP 88	P.M.A. VAN ZYL GROOTE DRIFT 5 Grootdrif	32 23 59	18 28 23	4	D S G	C	7.5	480	95	5.7	sand	1	3	12	93-3-26

SITE ID.	SITE TYPE	OWNER CADASTRAL FARM FARM NAME	LATITUDE (D M S)	LONGITUDE (D M S)	ELEVN. (mamsl)	WATER USE	PUMP TYPE	YIELD (l/s)	ABSTRACT -ION (m3/yr)	E.C. (mS/m)	pH	GEOLOGY	WATER (mbs)	LEVEL (mamsl)	BH DEPTH	DATE
HR1 AD 87	DW	J.J.C. VD WESTHUIZEN ELANDS BAAI Hunter Street	32 18 47	18 20 28	11	W	C	?	?	235	7.3	sand + shelly gravel	8.55	2.45	10	93-3-25
HR2 AD 86	DW	G.J.M. MOUTON ELANDS BAAI 2 Hunter Street	32 18 50	18 20 29	5	G	C	?	150	254	7.4	sand	3	2	4	93-3-25
MK1 3218AD 85	BH	T.E. SMIT VERLOREN VLEI 8 Muishoek	32 21 55	18 26 29	4	S D Ip	S	?	?	149	6.4	sand + TMS	?	?	30	93-3-25
NS1 AD84	D	J.A. LOUW BONTEHEUVEL 1 Nuwerus	32 19 34	18 25 07	3	D Ip	C	?	?	100	7.1	sand	surface	3	2	93-3-25
R1 AD 83 (RE3)	BH	LOCAL COUNCIL / SANDVELD STATE FOREST GRAAUWE DUYNEN 231	32 17 41	18 21 40	23	M	S	1.5	29 960	58.7	6.8	sand (0-10m) sand+clay (10-40m)	21.65 *	1.35	31.5	93-3-24
R2 AD 82 (G33989A)	BH	LOCAL COUNCIL / SANDVELD STATE FOREST GRAAUWE DUYNEN 231	32 17 47	18 21 47	21	M	S	1	30 750	201 **	7.5	sand (0-9m, 15-29m) clay+calcrete (9-15m) clay+TMS (29-35m)	sealed	?	35	93-3-24
R3 3218AD (G33658A)	BH	LOCAL COUNCIL / SANDVELD STATE FOREST GRAAUWE DUYNEN 231	32 18 01	18 22 00	28.7	M	S	2	35 480	60	7	sand+silt (0-49m) TMS (49-120m)	27.06	1.64	61	93-3-24
SA1 AD 81	BH	D.J.B. SMIT ELANDS BAAI Swansea	32 19 10	18 20 29	16	S	S	0.7	210	930	7.2	sand TMS	?	?	46	93-3-25
SA2 AD80	D	D.J.B. SMIT ELANDS BAAI Swansea	32 19 01	18 20 42	3	S	?	?	?	630	8.1	sand	surface	3	2	93-3-25
UK1 AD 79	DW	P.J.A. V LITSENBORGH BONTEHEUVEL 1 Uithoek	32 20 53	18 26 51	4	D S	C	0.4	150	59.8	5.3	sand	0.43	3.57	2.8	93-3-26
VI1 AD 78	DW	T.E. SMIT VERLOREN VLEI 8 Boekpenskop	32 19 32	18 22 40	3	S	W	?	wind dependent	452	7.3	sand	0.4	2.6	2	93-3-25
VI2 AD 77	DW	T.E. COETZEE VERLOREN VLEI 8 Verlorevlei	32 19 38	18 22 22	4	D S	C	?	1 825	883	7.5	sand	2.5	1.5	4	93-3-25

* water level measured in adjacent monitoring borehole while production borehole was being pumped.

** considered dubious analysis since field measurement on 93-3-24 was 50mS/m and was tested at 56mS/m in June 1992.

SITE ID.	SITE TYPE	OWNER CADASTRAL FARM FARM NAME	LATITUDE (D M S)	LONGITUDE (D M S)	ELEVN. (mamsl)	WATER USE	PUMP TYPE	YIELD (l/s)	ABSTRACT -ION (m3/yr)	E.C. (mS/m)	pH	GEOLOGY	WATER (mbs)	LEVEL (mamsl)	BH DEPTH	DATE
VI3 AD 76	DW	J.N. COETZEE VERLOREN VLEI 8 Verlorevlei	32 19 38	18 22 24	3	D S	C	?	910	544	7.8	sand	2.5	0.5	4	93-3-25
VI4 3218 AD 75	WP	J.N. COETZEE VERLOREN VLEI 8 Verlorevlei	32 19 36	18 22 23	3	D	C	?	105	1029	7.3	sand	2	1	4	93-3-25
WK1 AD74	DW	J.D. LOUW BONTEHEUVEL 1 Waaihoek	32 19 15	18 24 20	3	D S G	W	?	wind dependent	116	7.9	sand	4.99	-1.99	7	93-3-25

DWA&F Boreholes

SITE ID.	SITE TYPE	OWNER CADASTRAL FARM FARM NAME	LATITUDE (D M S)	LONGITUDE (D M S)	ELEVN. (mamsl)	WATER USE	PUMP TYPE	YIELD (l/s)	ABSTRACT -ION (m3/yr)	E.C. (mS/m)	pH	GEOLOGY	WATER (mbs)	LEVEL (mamsl)	BH DEPTH	DATE
G31294 3218AD73	BH	GRAAUWE DUYNEN 231 (exploration)	32 17 47	18 21 35	19.9	N	N	?	0	?	?	qtzitic sand (0-8m) gravelly sand (8-60m) muddy sand (60-81m) TMS (81-109m)	18.75	1.18	109	~1980 (drilled)
G31295 AD72	BH	BONTEHEUVEL 1 (exploration)	32 20 08	18 25 55	7.6	N	N	?	0	?	?	qtzitic sand (0-17m) gavelly sand (17-42m) TMS (42-67m)	~8	-0.4	67	8-80 (drilled)
G33568 AD6	BH	BONTEHEUVEL 1 (exploration)	32 18 24	18 25 17	42.7	N	N	0.1	0	23	5.1	sand (0-22m) clay (22-37m) gravelly sand (37-60m)	13.7	29	60	06-87 (drilled)
G33569 AD71	BH	BONTEHEUVEL 1 (exploration)	32 18 34	18 24 50	42.7	N	N	0.4	0	432	7.2	sand (0-31m) clay (21-28m) weathered TMS (31-99m) TMS (99-122m)	26.9	15.8	122	07-87 (drilled)
G33651 AD10	BH	BONTEHEUVEL 1 (exploration)	32 20 10	18 27 23	22.9	N	N	0.1	0	111	6.3	sand (0-21m) sandy gravel (21-41m) sandy silt (41-63m)	13.4	9.5	63	07-87 (drilled)
G33652 AD9	BH	BONTEHEUVEL 1 (exploration)	32 18 03	18 22 07	28.5	N	N	1.5	0	60	7.3	sand (0-29m) gravelly sand (29-47m) sand (47-56m)	26.9	1.6	56	07-87 (drilled)
G33653 AD8	BH	GRAAUWE DUYNEN 231 (exploration)	32 17 35	18 22 00	36	N	N	1.5	0	57	7.2	sand + silt (0-38m) coarse sand (38-43m) silt + clay (43-60m)	34.1	1.9	60	08-87 (drilled)
G33654 AD70	BH	BONTEHEUVEL 1 (exploration)	32 18 34	18 21 57	12	N	N	0.2	0	3498 ***	7.7	sand (0-4m) sandy gravel (4-37m) clay (37-46m)	10.9	1.1	46	08-87 (drilled)
G33659 AD11	BH	BONTEHEUVEL 1 (hole abandoned)	32 19 59	18 27 46	57.9	N	N	?	0	?	?	sand (0-57m) clay (35-37m) weathered TMS (57-102m)	45.3	12.6	102	11-87 (drilled)

*** highly anomalous value - considered either to be localised body of connate water or dubious laboratory analysis

APPENDIX B

SURFACE WATER HYDROCENSUS DATA

SITE ID.	SITE TYPE	CADASTRAL FARM FARM NAME	LATITUDE (D M S)	LONGITUDE (D M S)	pH	E.C. (mS/m)
VV1 78	V	BONTEHEUVEL 1 Klein Bontheuwel	32 18 55	18 22 40	8.8	471
VV2 77	V	ELANDS BAAI Die Mond	32 19 02	18 20 11	7.8	>2000
VV3 AD 76	V	ELANDS BAAI Die Mond	32 18 57	18 20 00	8.4	6830
VV4 AD75	V	VERLOREN VLEI 8 Danielsdrif	32 18 55	18 21 21	8.8	505
VV5	V	VERLOREN VLEI 8 Boekpenskop	32 19 30	18 22 40	9.1	378
VV6	V	BONTEHEUVEL 1 Nuwerus	32 19 35	18 25 09	8.6	230
VV7	V	BONTEHEUVEL 1 Klein Bontheuwel	32 18 58	18 23 55	7.7	89.9
VV8	V	BONTEHEUVEL 1 Uithoek	32 20 58	18 26 45	8.4	220
VV9	V	VERLOREN VLEI 8 Muishoek	32 21 55	18 26 31	7.7	240
VV10	V	GROOTE DRIFT 5 Grootdrif	32 23 54	18 28 27	7.4	340
C1	S	ELANDS BAAI Die Mond	32 18 54	18 20 01	7.8	4368

APPENDIX C

WATER QUALITY ANALYSES

LEGEND

Limit A	:	• maximum recommended limit for no risk i.e. ideal level • drinking water conforming to this limit is expected to be safe for lifetime consumption
Limit B [1]	:	• maximum recommended limit for insignificant risk • drinking water conforming to this standard is not ideal but poses negligible risk to human health, even for lifetime consumption
TDS	:	total dissolved salts
NH_4	:	ammonium as nitrogen (N)
$NO_3 + NO_2$	:	nitrate and nitrite reported as equivalent molecular nitrogen (N) where 1 mg/ℓ N = 4.5 mg/ℓ NO_3
TAL	:	total alkalinity as $CaCO_3$
PO_4	:	ortho-phosphate (inorganic) as phosphorous (P)

- All values in mg/ℓ (ppm) except : pH - logarithm of the inverse of the hydrogen (H^+) ion concentration, therefore dimensionless, and EC - electrical conductivity (a measure of salinity) in milli-Siemens per metre @ 25° C.
- The shaded values exceed the maximum allowable limit for water used for domestic purposes
- The analyses were carried out at the Hydrological Sciences Institute (HRI) of DWA&F in Pretoria.

*** The macro analyses indicate general fitness for use only and should not be considered definitive indications of acceptability for consumption. Further tests to determine the concentration of potentially harmful substances, such as the coliform bacteria, need to be done.*

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1 • Limits A + B after Aucamp et al. (1990) except limits for PO_4, Si + NH_4 after Kempster et al. 1980
• Limit B equivalent to target guideline range of DWA&F (1993) in which little or no health effects occur.

SITE ID.	SITE TYPE	DATE SAMPLED	H-NUMBER	pH	EC	TDS	NH4 (N)	NO3+NO2 (N)	F	TAL (CaCO3)	Na	Mg	Si	PO4 (P)	SO4	Cl	K	Ca
LIMIT A				6-9	70	500	0	6	0.5	20-300	100	70		0.06	200	250	200	150
LIMIT B			9300..	5.5-9.5	300	2000	0.5	10	1.5	650	400	100	18	0.1	600	600	400	200
BH3	DW	93-3-24	4941	7.5	51.1	292	0.08	14.05	0.2	19	55	9	6	0.66	30	78	11.5	23
BH5	BH	93-3-24	4928	7.9	101.2	497	0.06	2.54	0.3	11	152	18	4.1	0.016	33	257	3	9
BH6	WP	93-3-25	4930	7.8	114.8	638	0.04	7.13	0.2	35	164	23	6.5	0.95	46	285	12	30
BL1	BH	93-3-24	4965	7.7	356	2124	0.19	7.95	0.3	38	638	73	5.5	0.119	140	1127	22.3	41
BL2	DW	93-3-24	4953	7.9	212	1251	0.08	14.05	0.4	52	319	37	5.5	0.277	112	577	20.9	58
GF2	BH	93-3-26	4795	7.1	155	792	0.06	2.44	0.2	14	250	23	4.5	0.005	45	427	8.5	11
HR1	DW	93-3-25	4989	6.9	235	1453	0.12	16.07	0.4	247	307	61	8.2	0.074	68	535	18.4	91
HR2	DW	93-3-25	4990	7.5	254	1493	1.08	1.08	0.5	251	355	60	6.4	0.34	31	650	9.1	74
MK1	BH	93-3-26	4801	7.5	149	763	0.09	6.78	0.1	23	210	34	5.2	0.005	41	391	8.1	20
R1	BH	93-3-24	4850	8	58.7	374	0.05	6.86	0.2	122	44	6	6.1	0.007	13	70	2.8	60
R2	BH	93-3-24	4862	8.2	201	1120	0.1	0.05	0.3	97	287	51	3.1	0.011	48	569	6.8	39
UK1	DW	93-3-26	4813	6.9	59.8	276	<0.04	5.08	0.2	<4	72	15	4.4	<0.005	7	148	3.6	7
VI1	DW	93-3-25	4898	8.3	452	2909	0.08	9.98	0.3	223	743	117	8.7	0.373	234	1356	17.5	125
VI2	DW	93-3-25	4886	8.2	883	5942	0.17	23.61	0.3	265	1521	230	9.9	0.555	370	2984	177.8	229
VI3	DW	93-3-25	4874	8.3	544	3458	0.09	1	0.2	274	856	121	12.4	1.73	185	1703	97	152
VI4	WP	93-3-25	4904	8.4	1029	7305	0.14	34.73	0.3	368	1854	272	9.8	0.028	446	3587	288.2	255
WK1	DW	93-3-25	4837	8	116.2	668	<0.04	13.67	0.2	60	154	16	6.1	0.419	88	222	11.6	41
NS1	D	93-3-25	4849	7.5	87.8	433	0.07	5.66	0.2	9	123	19	4.3	0.01	27	211	4.4	12
SA2	D	93-3-25	4825	8	596	3488	0.13	0.06	0.3	164	964	150	<0.4	0.008	187	1864	21.8	10
VV1	V	93-3-24	5003	7.3	471	2867	0.08	0.07	0.5	196	786	129	<0.4	0.045	79	1555	10.3	67
VV3	V	93-3-25	5015	8.1	6830	70332	0.57	0.05	0	111	21346	2456	2.6	0.023	5528	39305	741.7	819
VV4	V	93-3-25	5027	7.6	505	2732	0.16	0.05	0.6	162	746	126	<0.4	0.022	112	1473	12	64
VV5	V	93-3-25	5039	7.7	378	2170	0.14	0.3	0.4	133	589	96	0.8	0.018	96	1152	9.2	64
VV7	V	93-3-25	5052	5.4	89.9	422	0.09	2.04	0.3	22	109	17	<0.4	0.035	31	202	6.9	19
VV10	V	93-3-26	5064	7.2	340	2103	0.06	0.29	0.4	199	568	97	2.3	0.025	24	1102	6	60
C1	S	93-3-25	4916	8.1	4368	36138	0.48	0.27	0.9	118	11042	1469	0.8	0.014	2648	19919	470.2	443